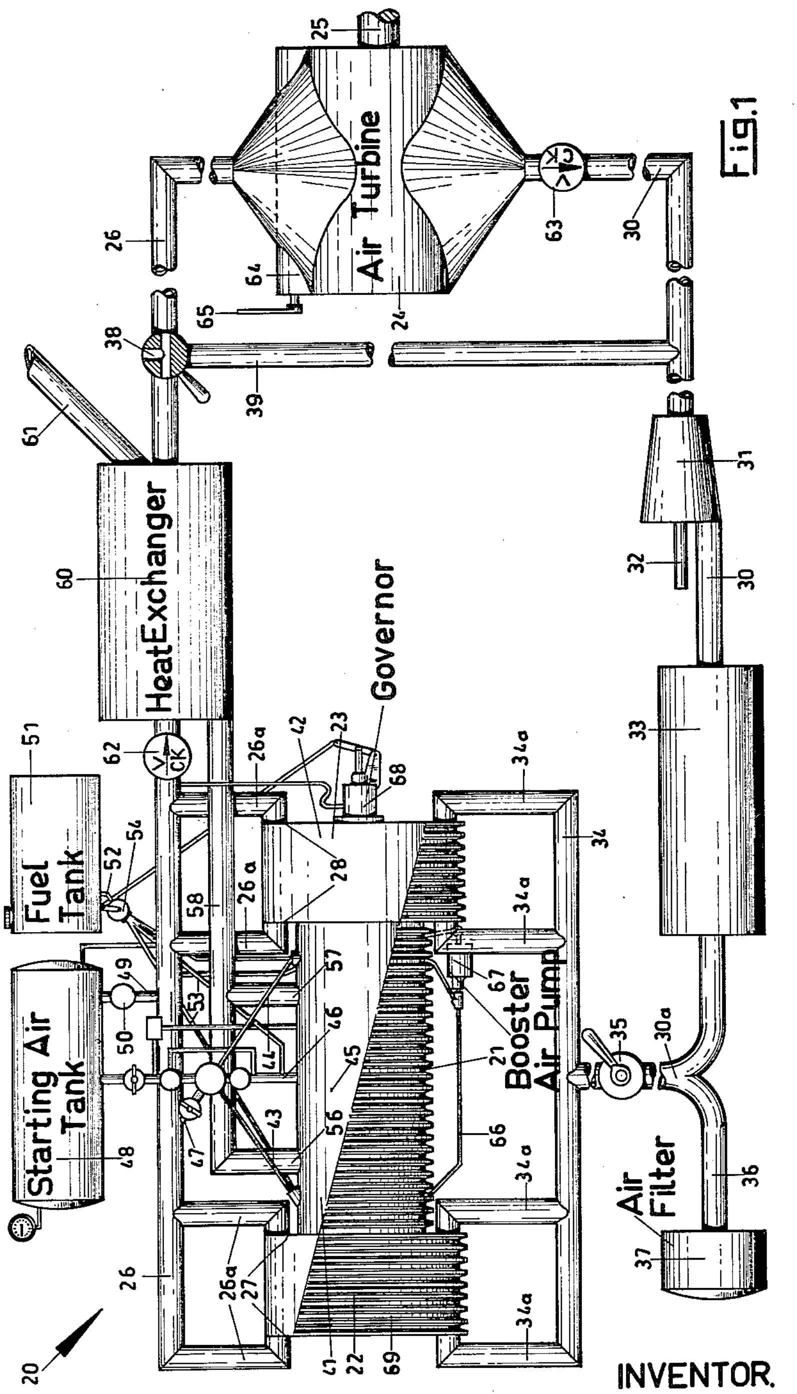
June 11, 1963 | A. W. DUNCAN | 3,092,958

FREE PISTON ENGINE

Filed Sept. 11, 1961 | | 6 Sheets-Sheet 1



INVENTOR.

Andrew William Duncan

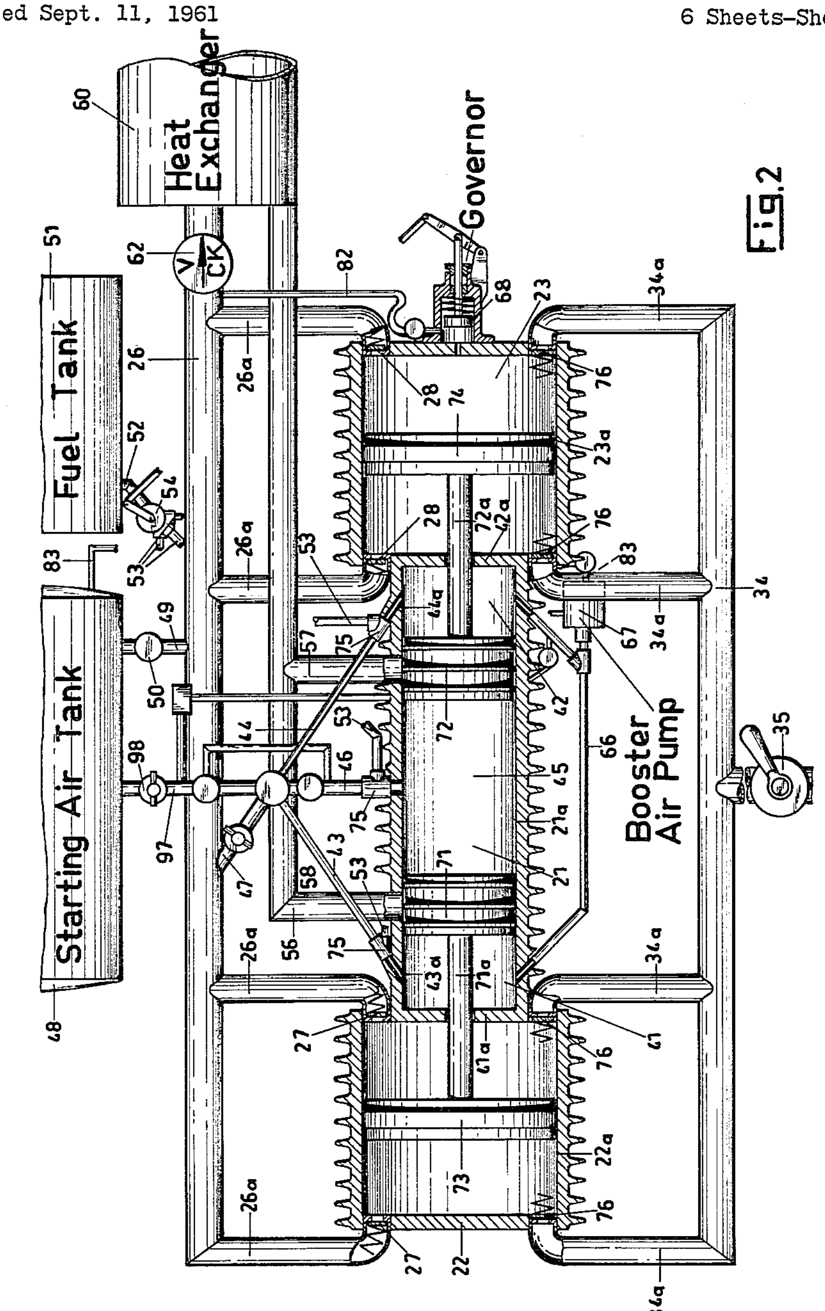


Fig. 2

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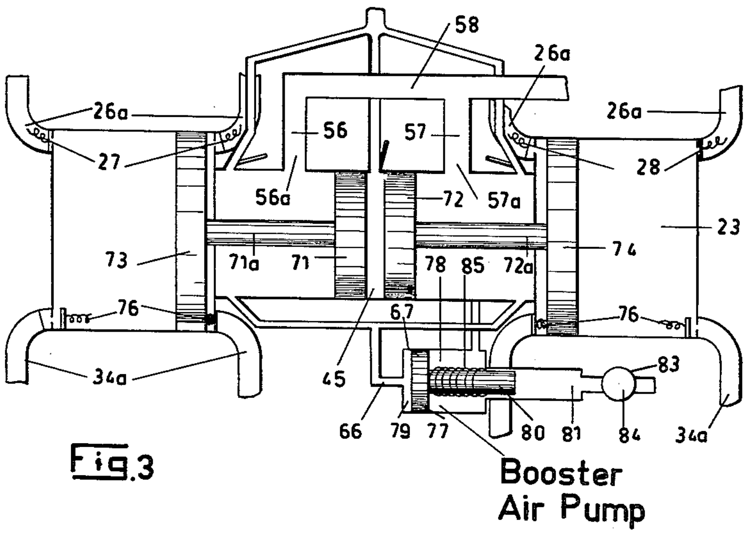

Fig.3

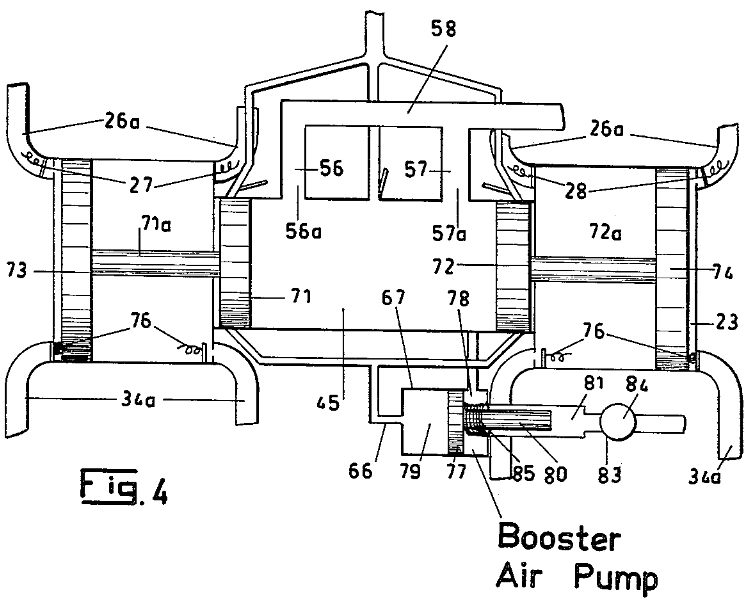

Fig.4

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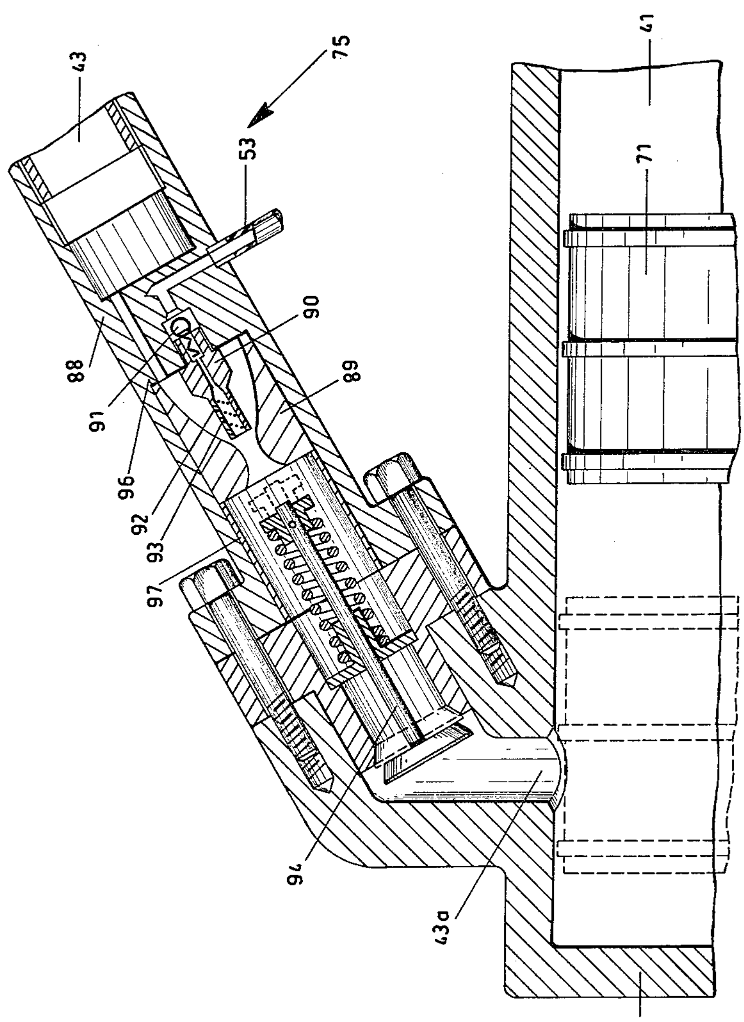
Fig. 5



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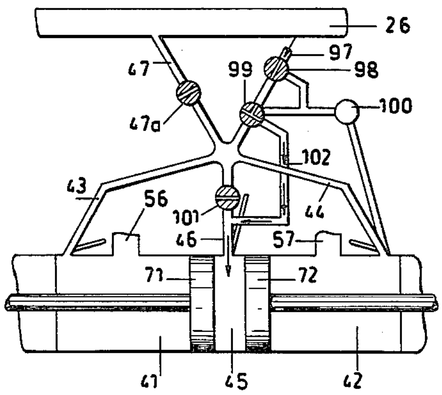

Fig. 6

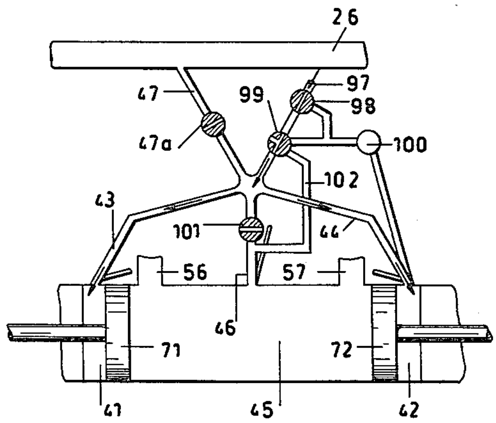

Fig. 7

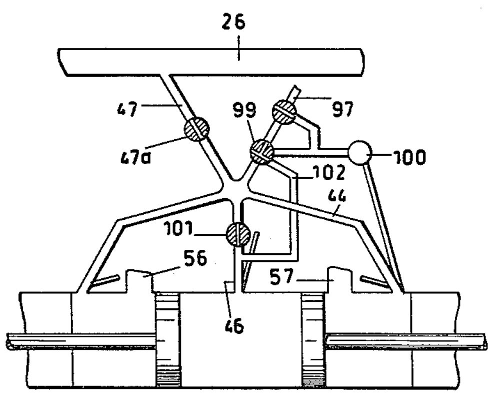

Fig. 8

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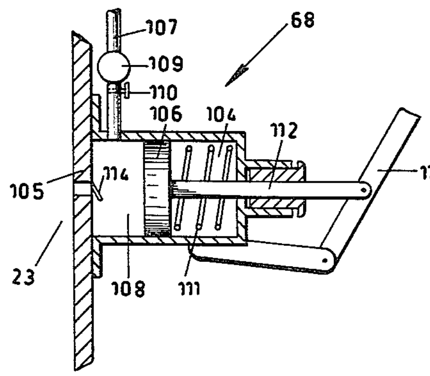

Fig. 9

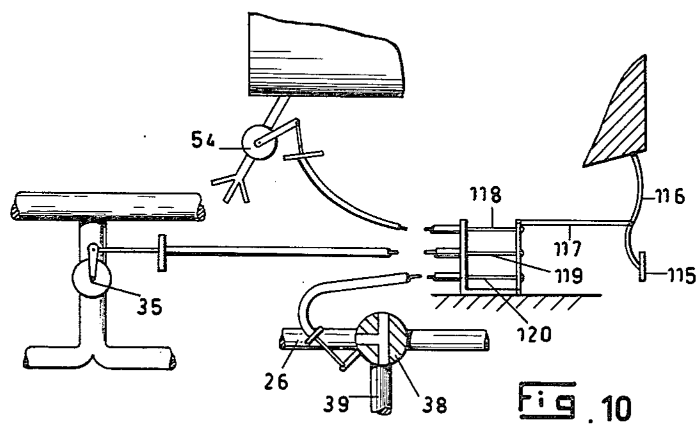

Fig. 10

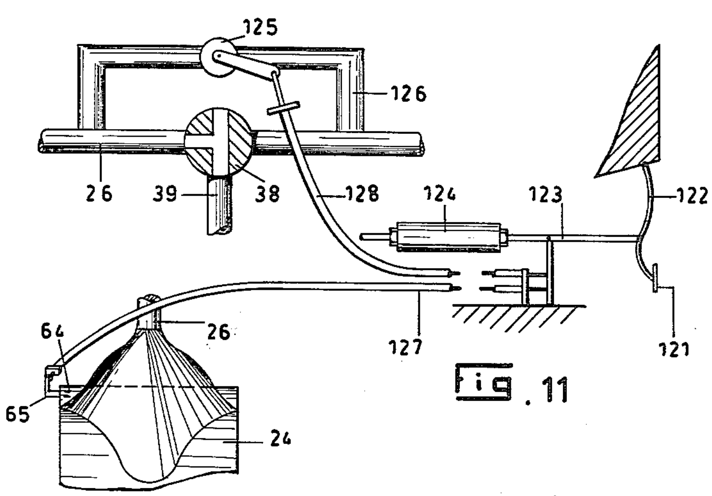

Fig. 11

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3,092,958
FREE PISTON ENGINE

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Filed Sept. 11, 1961, Ser. No. 137,207
14 Claims. (Cl. 60—14)

This invention relates to improvements in internal combustion engines, and more particularly to improvements in free piston engines.

It is well known in the art to utilize piston engines of the free stroke type as gas generators for prime movers such as, for instance, turbine motors. Conventional engines of this type generally comprise one or two pistons reciprocating within a cylinder and, due to the absence of the flywheel effect of a crankshaft assembly, utilize instead a cushion of compressed air to return each piston to perform its compression stroke. This air cushion is formed either between the piston and the end wall of the cylinder or within an air pump driven by the piston. In either case there is a considerable energy wastage in creating an air cushion of sufficient magnitude to accomplish the return stroke of the piston, and in the latter case, where part of the air pump is used, another disadvantage lies in the fact that only one effective pumping stroke per cycle is possible.

Other disadvantages of engines of the prior art are that they operate at extremely high temperatures, thus necessitating the use of expensive, high duty metal alloys and the like in their construction; and, in many instances, exhaust gases are used to increase the volume of compressed air passing to the prime mover, with consequent deleterious effects upon the internal mechanism of the prime mover. This makes it necessary to embody the prime mover in close proximity to the engine in order to fully utilize the heat value of the exhaust gases.

Furthermore, substantially all free piston engines of the prior art operate on compression-ignition, utilizing injectors of the diesel engine type to supply fuel to the cylinder at the appropriate moment of the compression stroke. This adds to the complexity of the machine by requiring timing and pump mechanism for the injectors and, therefore, also adds to its vulnerability to mechanical defects.

It is an object of the present invention to provide a free piston engine in which every stroke is a combined compression stroke and power stroke, thereby eliminating the necessity for a power-absorbing air cushion.

It is another object of the invention to provide a free piston engine in which energy from combustion is transferred directly into kinetic energy of the pistons therein, and, due to the positioning of the exhaust ports, all of said kinetic energy for substantially half the length of stroke of said pistons, is utilized in compressing air in the compressors driven by said pistons.

It is a further object of the invention to provide a free piston engine which, by having two pistons, each operating a double acting air pump, and two power strokes per cycle, will thereby produce four air pumping strokes per cycle.

It is yet another object of the invention to provide a free piston engine which, due to its immediate heat energy absorption which is directly transferred to the air pumps without any intervening mechanical losses and very little frictional loss, has an increased thermal efficiency over that of conventional engines, thereby utilizing more released heat to perform useful work, which results in less heat wastage and, therefore, a cooler running engine.

It is a further object of the present invention to provide a free piston engine which will further add to its thermal efficiency by passing the exhaust gases therefrom through a heat exchanger which will raise the temperature of the compressed air, thereby increasing its volumetric flow through the prime mover.

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It is still another object of this invention to provide a free piston engine which, as previously stated, utilizes the exhaust gases to raise the compressed air temperature only, before passing to atmosphere and, therefore, gains energy from said gases without mixing them with the air passing through the prime mover.

It is yet another object of the invention to provide a free piston engine which, although operating on compression ignition, will eliminate the pumping and timing mechanisms of diesel-type injectors by utilizing a combined air-fuel charging valve automatically controlled by cylinder pressure.

It is a further object of the present invention to provide a free piston engine having suitable control means to enable it to be used equally efficiently over a wide range of applications.

It is still another object of the present invention to provide a free piston engine which may be operated remotely from its associated prime mover with only a very slight loss in efficiency.

Thus, from the foregoing objects it may be seen that a principal object of the invention is to provide a free piston engine having a high power-weight ratio, thereby permitting it to be much smaller in size and weight than a comparably powered engine of the prior art, and due to its cool running properties, it may be fabricated utilizing less expensive metals, thereby cutting manufacturing costs considerably.

These and other objects and features of this invention will become apparent when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic layout of a power plant embodying a free piston engine of the present invention having a gas turbine as a prime mover.

FIG. 2 is a sectional side elevation of the engine illustrated in FIG. 1 showing particularly the general construction and relative positions of the engine and compressor components.

FIG. 3 is a diagrammatic sketch of the engine shown in FIG. 2, illustrating particularly the pistons contained therein approaching each other to achieve compression ignition within the centre cavity of the cylinder. Also illustrated are the compressor units, reaching the end of one cycle, and an auxiliary air pump is shown at the end of an induction stroke.

FIG. 4 is a diagrammatic sketch of the engine shown in FIG. 2 illustrating particularly the pistons contained therein approaching the end walls of the cylinders to achieve synchronized compression ignition within the end cavities of the cylinder. The compressors are also shown after having reached the end of an opposite cycle to that shown in FIG. 3 and the auxiliary air pump is illustrated at the completion of its compression stroke.

FIG. 5 is a sectional side elevation of a cylinder charging valve embodied in the present invention.

FIG. 6 is a diagrammatic sketch illustrating the initial movement in starting the engine and one phase of the starting cycle.

FIG. 7 is a diagrammatic sketch illustrating the second movement in starting the engine and the opposite phase of the starting cycle to that shown in FIG. 6.

FIG. 8 is a diagrammatic sketch showing the condition of the induction system after the engine has been started and switched to normal operation.

FIG. 9 is a sectional side elevation of an engine speed governor mechanism which may be incorporated in the control system of the present invention.

FIG. 10 is a diagrammatic layout of a control system for the power plant illustrated in FIG. 1 when used as motive power for an automobile.

FIG. 11 is a diagrammatic layout of a brake system embodied in conjunction with the control system shown in FIG. 10.

Referring to FIG. 1, a power plant 20 includes a free piston engine assembly 21 driving two air compressors 22 and 23 adapted to provide air in sufficient volume and at a high enough pressure to actuate a gas turbine engine 24 of the reaction type.

A power take-off shaft 25 extends outwardly from turbine 24 to convert the power developed within power plant 20 to useful work.

Suitable ducting 26 interconnects compressors 22 and 23 with turbine engine 24, a plurality of branch ducts 26*a* being adapted to convey compressed air from the pressure air outlets 27 of compressor 22 and similar outlets 28 of compressor 23 into ducting 26.

Pressure air, having passed through turbine engine 24 is thereafter collected and passed through an outlet duct 30 in which is interposed an auxiliary axial flow turbine engine 31 having a take-off shaft 32. Shaft 32 is utilized for driving accessories such as generators, pumps and the like.

Air from the outlet of turbine 31 is then ducted through a cooler 33 prior to its recirculation through compressors 22 and 23 via an inlet manifold 34 and a plurality of branch pipes 34*a*.

An air flow control valve 35 is located in the portion 30*a* of duct 30 joining with manifold 34.

An additional air inlet duct 36 joins end portion 30*a* of duct 30 to provide for the admission of air from atmosphere to implement that already in circulation, this compensating for air leaks and for the varied volumes of air pumped during varying engine conditions. An air filter 37, attached to the open end of duct 36, ensures substantially clean air being circulated throughout the compressor system.

It should also be noted that end 30*a* of duct 30 and duct 36 join at an angle to prevent air being ejected from duct 30 through duct 36 instead of continuing through manifold 34. An internal baffle at this junction point also serves to create a venturi effect so that flow of air from duct 30 also induces air to enter the system through duct 36.

A two-way valve 38 in duct 26 permits selective direction of pressure air from compressors 22 and 23 either through main turbine 24, when it is required to operate main drive shaft 25, or through a by-pass duct 39 to join outlet duct 30 without passing through turbine 24 when it is required to keep engine 21 running without any power take-off from shaft 25.

By-pass duct 39 joins outlet duct 30 before auxiliary turbine 31 so that, during the by-pass operation, shaft 32 will continue to operate the auxiliary components of power plant 20.

During normal running of engine 21, air is supplied to the end combustion chambers 41 and 42 by pressure pipes 43 and 44 respectively and to the centre combustion chamber 45 by a larger pipe 46. A common supply duct 47 interconnects said pipes 43, 44 and 46 with air pressure duct 26 so that a constant supply of compressed air is available for use in engine 21 during the running thereof.

A compressed air tank 48 is utilized for starting purposes, tank 48 being filled with pressure air from duct 26 through a supply pipe 49 and a check valve 50. Fuel is supplied to engine 21 from a tank 51 through an outline pipe 52 branching out to a plurality of fuel lines 53 which, in a manner herein described, join air pressure pipes 43, 44 and 46 adjacent engine 21. A fuel cock 54 is located in outlet pipe 52 and is adapted to control the supply of fuel to engine 21 through pipes 53.

Exhaust from engine 21 is taken therefrom by two exhaust pipes 56 and 57 joining a common exhaust manifold 58 and from there is utilized to raise the temperature of the air in duct 26 by passing through a heat exchanger 60, ultimately passing to atmosphere through a tail pipe 61.

It should be noted that the exhaust gases merely heat the pressure air in duct 26 and do not mix therewith.

A pressure maintaining check valve 62 is located in duct 26 between the location at which branch ducts 26*a* join duct 26 and two-way valve 38 in order to ensure adequate air pressure being available at all times for supply to engine 21.

A check valve 63 is also located in outlet duct 30 from turbine 24 to prevent back pressure air moving into and reversing turbine 24 upon two-way valve 38 being selected to the by-pass position.

An air distribution valve 64 of cylindrical configuration is interposed between air duct 26 and the inlet to turbine 24 and is adapted to direct pressure air from duct 26 to drive turbine 24 in either direction as selectively operated by its lever 65.

Other components illustrated in FIG. 1 and to be hereinafter described are: a pressure balance pipe 66 adapted to extend between opposite ends of engine 21; a booster air pump 67 operable by pressures in said balance pipe 66 and adapted to raise air pressure in tank 48 in excess of that supplied thereto from duct 26; and an engine governor 68 adapted to control the speed of engine 21 to provide the necessary air pressure within duct 26 as determined by pressure loaded check valve 62.

It should also be noted in FIG. 1 that engine 21 and compressors 22 and 23 are shown having fins 69 extending outwardly therefrom for cooling purposes. This, however, is not intended in any way to limit the scope of the invention which may be provided with any other type of cooling, such as liquid cooling, in lieu of the finning shown herein.

Referring to FIG. 2, engine 21 includes a cylindrical body 21*a* having two oppositely located end walls 41*a* and 42*a* defining the outer limits of end combustion chambers 41 and 42 respectively as shown in FIG. 1.

Two pistons 71 and 72 are located in cylinder 21*a* and are adapted to reciprocate therein in opposite directions, the space between said pistons forming centre combustion chamber 45.

A piston rod 71*a* extends outwardly from piston 71 substantially coaxially therewith and with cylinder body 21*a* and passes through end wall 41*a* of combustion chamber 41 in sealed, slidable contact therewith to terminate in a compressor piston 73. Piston 73 is housed within cylindrical body 22*a* of compressor 22 and is adapted to reciprocate therein in direct unison with piston 71 within cylinder 21*a*.

A similar piston rod 72*a* extends outwardly from piston 72 through end walls 42*a* of combustion chamber 42, into the cylindrical body 23*a* of compressor 23 to terminate in a compressor piston 74 thus movement of pistons 71 and 72 within cylinder 21*a* of engine 21 results in a similar reciprocal motion of pistons 73 and 74 in compressors 22 and 23 respectively.

Pistons 71 and 72 are of identical size and weight, each being substantially wider than their respective associated exhaust ports 56*a* and 57*a* leading to pipes 56 and 57 respectively.

An air and fuel charge is supplied to combustion chambers 41, 42 and 45 by means of a plurality of cylinder charging valve 75, one of which is installed in each air pressure pipe 43, 44 and 46 adjacent body 21*a* of engine 21. A fuel line 53 joins each charging valve 75 so that an atomized mixture of fuel and air is supplied substantially continuously to chambers 41, 42 and 45.

Referring also to FIG. 3, it will be seen that upon pistons 71 and 72 traveling inwardly of body 21*a* the fuel air mixture in chamber 45 is compressed rapidly and progressively and, upon the pistons 71 and 72 coming into close proximity, the mixture compressed therebetween is caused to ignite on the normal principle of compression ignition.

Upon combustion occurring in chamber **45** the pressure generated therein causes pistons **71** and **72** to move outwardly and, as shown in FIG. 3, the location of exhaust pipes **56** and **57** is such that over substantially half the stroke of pistons **71** and **72** there is virtually no opposition to the movement thereof within cylinder **21***a*. This, it should be noted, occurs at the time when the greatest pressure from combustion is applied to pistons **71** and **72** and, therefore, large percentage of the energy released by the burning of the fuel in chamber **45** is transferred into kinetic energy of pistons **71** and **72**.

During the latter half of their respective outward strokes pistons **71** and **72** initially cover exhaust ports **56***a* and **57***a* respectively, so that the fuel air mixture in end chambers **41** and **42** is thereafter compressed upon further outward movement of pistons **71** and **72**. Upon pistons **71** and **72** moving past ports **56***a* and **57***a* on the outward portion of the strokes, pressurized air and fuel mixture from the centre charging valve **75** in pressure pipe **46** enters chamber **45** at the centre thereof, and thereafter expands outwardly to force the burned gases from chamber **45** causing them to pass out of exhaust ports **56***a* and **57***a*, and, at the same time, refilling centre chamber **45** with a fuel air mixture for subsequent compression and ignition.

At the same time, the energy imparted to pistons **71** and **72** is utilized in compressing the fuel air mixture in end chambers **41** and **42** respectively and, as also shown in FIG. 4, at the end of their outward strokes pistons **71** and **72** completely cover the apertures **43***a* and **44***a* connecting pipes **43** and **44** respectively to combustion chambers **41** and **42** respectively.

The compression of the fuel air mixture in end chambers **41** and **44** again results in the spontaneous combustion thereof, so that pistons **71** and **72** are caused to reverse and move inwardly under the pressure generated in said end chambers **41** and **42**. It will be noted from FIG. 4 that again exhaust ports **56***a* and **57***a* are uncovered so that the initial inward movement of pistons **71** and **72** within body **21***a* is again substantially unrestricted within engine **21** so that maximum benefit may be derived from the combustion of the fuel air mixture by imparting kinetic energy to pistons **71** and **72** at the period where such energy is highest.

Upon traversing substantially half the distance of their strokes pistons **71** and **72** again cover exhaust ports **56***a* and **57***a* respectively and begin compressing the mixture in centre chamber **45** as previously described. Further inward travel of pistons **71** and **72** again opens exhaust ports **56***a* and **57***a* to end chambers **41** and **42** respectively, permitting the burned gases to escape therefrom aided by the incoming compressed air and fuel mixture from their respective charging valves **75**.

Balance pipe **66** as shown in FIG. 1, is adapted to interconnect end combustion chambers **41** and **42**, thereby equalizing the pressures generated therein and ensuring synchronized action of pistons **71** and **72**.

The reciprocating action of pistons **71** and **72** as herein described results in a similar reciprocating action of pistons **73** and **74** within compressors **22** and **23** respectively.

A plurality of lightly loaded inlet valves **76** are located in cylinders **22** and **23**, on opposite sides of pistons **73** and **74** and are adapted to communicate branch pipes **34***a* of inlet manifold **34** with compressors **22** and **23**. Air pressure outlets **27** and **28** as previously described are also located in the walls of compressors **22** and **23** respectively and also include lightly loaded plate valves in communication with branch ducts **26***a* of outlet compressed air duct **26**.

Thus, reciprocation of pistons **71** and **72** results in similar reciprocation of pistons **73** and **74** within compressors 22 and 23, air being drawn into compressors **22** and **23** on one side of the pistons **73** and **74** respectively while air is compressed and expelled through the outlet ducts located in compressors **22** and **23** as described on the opposite side of pistons **73** and **74**. Similar action occurs on return strokes of pistons **73** and **74** so that each compressor **22** and **23** delivers a maximum amount of air under pressure with each stroke of pistons **71** and **72** of engine **21**.

The action of booster air pump **67** is also illustrated in FIGS. 3 and 4, pump **67** including a piston **77** and cylinder **78**, the upper cavity **79** of said cylinder **78** being in communication with pressure balance pipe **66** so that piston **77** is influenced by the varying pressures in pipe **66** and, therefore, is affected by the operating pressures of end combustion chambers **41** and **42**. A piston rod **80** extends outwardly from piston **77** to operate in a compression chamber **81**. An air pipe **82** communicates the side of compression chamber **81** with pressure air from duct **26** while the end of chamber **81** is connected with compressed air tank **48** through a pipe **83** in which a check valve **84** is located. A light spiral spring **85** is adapted to bias piston **77** toward cavity **79** and the inlet from balance pipe **66**.

In operation, pistons **71** and **72** being on compression in centre combustion chamber **45** of engine **21** as shown in FIG. 3, combustion chambers **41** and **42** are operating their exhaust strokes and therefore compression therewithin is at a minimum so that piston **77** of pump **67**, under the influence of spring **85**, is in its fully retracted position adjacent the inlet from pipe **66** and piston rod **80** is sufficiently removed from chamber **81** to permit air pressure through line **82** to enter chamber **81**.

At the opposite end of the strokes of pistons **71** and **72**, pressure in end combustion chambers **41** and **42** increases to maximum working pressure and, therefore, the pressure in balance pipe **66** is at a maximum, so that pressure air entering cavity **79** forces piston **77** outwardly, overcoming spring **85** and piston rod **80**, which after initially closing off the entry of inlet pipe **82**, moves the air trapped in chamber **81** outwardly through check valve **84** and pipe **83** to compressed air tank **48**.

Due to the fact that engine **21** has an extremely rapid cycle of operation, pump **67** continues to increase the pressure within tank **48** and maintain it at a maximum, said maximum pressure being determined by a conventional relief valve or the like.

Referring to FIGS. 2 and 5, the construction and operation of a cylinder charging valve **75** is illustrated, in which a cylindrical body **88** is attached to, in this particular case, pressure air supply pipe **43** adapted to supply end chamber **41** through an orifice **41***a* as previously described. Air passing through pipe **43** and cylindrical body **88** is caused to move through a venturi sleeve **89** in which is interposed a fuel jet **90**. Jet **90** is supplied with fuel from tank **51** through the appropriate fuel pipe **53**, said fuel being ducted to the centre of jet **90** through a small, spring loaded ball valve **91** which permits little or no restriction of fuel flowing into jet **90** during normal running operations but is adapted to prevent fuel leakage upon engine **21** being stopped. A cylindrical nozzle **92** extends outwardly from jet **90** into the neck of venturi **89**, and a plurality of holes **93** drilled diagonally in the direction of flow of the pressure air and in a spiral configuration around nozzle **92**, permits said pressure air to enter nozzle **92** and effect complete and rapid atomization of the fuel prior to the fuel air mixture entering end chamber **41**. A spring loaded poppet type valve **94** is adapted to seal off the exit from body **88** of valve **75** and to prevent pressure blow back from chamber **41**, and conversely, permits the flow of pressure air and fuel into chamber **41** upon piston **71** uncovering exhaust port **56***a*. It should also be noted that orifice **43***a* is spaced apart from end wall **41***a* of combustion chamber **41** so that piston **71** protects valve **94** from the full pressure and heat developed in chamber **41** upon the fuel air mixture igniting.

It should be noted that the throat 95 of venturi 89, being the narrowest portion within body 88 of valve 75, meters the air flow passing through valve 75 and is adapted to provide sufficient air and fuel to support engine 21 at a predetermined frequency of operation. Thus, tendency of engine 21 to overspeed results in an insufficient quantity of fuel and air being delivered to the combustion chambers with the resultant slowing down of speed of operation. Cylinder charging valve 75, therefore, is adapted to permit venturi 89 to be easily changed, it being held in position by a shoulder 96 formed in body 88 at the one end and by a distance sleeve 97 located within body 88 at the opposite end.

Thus, it may be seen, that cylinder charging valve 75 provides a correctly proportioned and atomized mixture of fuel and air to combustion chamber 41 and also regulates the maximum frequency of operation of engine 21.

The oppositely located charging valve 75 serving end combustion chamber 42 is substantially identical to that described. The charging valve 75 serving centre chamber 45, however, is proportionally larger due to the fact that the combustion space between pistons 71 and 72 is substantially twice that of the combustion space in either chamber 41 or chamber 42. In the majority of other respects however the valve 75 serving centre chamber 45 is substantially identical to valve 75 herein described, its poppet valve 94, however, may be of somewhat more robust construction due to the fact that it is subjected to the pressures and temperatures of the compression ignition stroke within centre chamber 45.

Referring to FIGS. 2, 6 and 7, the starting cycle for engine 21 is illustrated, the object being to cut off pressure from manifold 26 through pipe 47 by means of an air cock 47*a* and to direct higher pressure air from tank 48 to end combustion chambers 41 and 42 simultaneously and to centre chamber 45 alternately therewith. To this end, a high pressure pipe 97 from tank 48 is connected to pipes 43 and 44 leading to end combustion chambers 41 and 42 respectively or to pipe 46 into centre chamber 45. To this end, a high pressure cock 98 is actuated to permit the pressure from tank 48 to enter a two-way valve 99 adapted to direct said pressure air either to pipe lines 43 and 44 simultaneously or to centre pipe 46 as determined by a pressure operated solenoid switch 100. Switch 100 is operated by pressure from end chambers 41 or 42, which may be taken from air balance pipe 66.

A further on-off cock 101 is required in the induction system as described to isolate centre air pipe 46 from end air pipes 43 and 44.

FIG. 6 illustrates the initial movement upon initiating the start for engine 21 when pressures are substantially at atmospheric, in which case solenoid switch 100 is adapted to divert high pressure air from tank 48 through a by-pass pipe 102 into centre pipe 36 and air therefore enters centre chamber 45 causing pistons 71 and 72 to move outwardly toward end chambers 41 and 42 respectively. Upon pistons 71 and 72 covering exhaust ports 56*a* and 57*a* respectively the pressures in chambers 41 and 42 build up so that, through the latter half of the compression strokes therein, switch 100 operates valve 99 and directs the high pressure air through pipe line 97 into end pipes 43 and 44 to enter end chambers 41 and 42. Pistons 71 and 72 are thus forced inwardly and upon passing their respective exhaust ports 56*a* and 57*a* the pressures within chambers 41 and 42 are substantially relieved and switch 100 moves valve 99 to direct pressure air through pipes 102 and 46 into centre chamber 45 substantially at the point of maximum compression therein.

Upon reaching the desired starting frequency the starting switch may be broken coinciding with the opening of air cock 47*a* in manifold pressure line 47 and the opening of on-off cock 101 in line 46, and simultaneously closing high pressure cock 98 and de-energizing solenoid switch 100, thus permitting engine 21 to continue to operate on manifold pressure from duct 26 as previously described.

Engine speed governor 68 as illustrated in FIGS. 1 and 2 is shown in greater detail in FIG. 9 and comprises a cylinder 104, an end wall 105 of which is in communication with the pressure air generated within compressors 22 and 23. A piston 106 is adapted to slidably operate within cylinder 104 and is suitably spring loaded to bias it toward end wall 105 thereof. A bleed line 107 communicates the chamber 108 defined by the crown of piston 106 and end wall 105 of cylinder 104 with duct 26, the amount of air bled therethrough being regulated by a non-return ball valve 109 and a regulating screw 110. The operating frequency of engine 21 is such that the pressures generated within compressors 22 and 23 are of a known ratio to the final pressure within duct 26 at the pressure side of pressure loaded check valve 62. Thus by controlling the amount of air bleeding through chamber 108 in governor 68, piston 106 may be held in a static position. As is conventional practice, a light coil spring 111 is adapted to bias piston 106 toward the fully closed position. Push rod 112 is substantially integral with piston 106 and is adapted to operate the control rod 113, which in turn is adapted to operate fuel cock 54 as shown in FIG. 2 so that, in operation, upon engine 21 tending to overspeed, pressure in chamber 108 of governor 68 builds up, overcoming the balance bleed to pipe 107 and therefore forcing piston 106 away from end wall 105 of cylinder 104. This outward travel of piston 106 is transmitted through push rod 112 and control rod 113 to close fuel cock 54 which, by cutting down the amount of fuel supplied to engine 21, reduces the speed thereof accordingly.

A conventional non-return valve 114 is located at the inlet to chamber 108 to permit pressure air from compressor 23 to enter chamber 108 and to ensure that piston 106 is not affected by the induction stroke of compressor 23 on that particular side.

Referring to FIG. 10, a proposed layout for accelerator controls is illustrated upon power plant 20 as herein described being utilized to propel a motor vehicle. To this end an accelerator pedal 115 is suspended in a conventional manner by means of an arcuately moving, hanging rod 116. A push rod 117 is pivotally attached to rod 116 and is adapted to transfer forward motion of pedal 115 to operate three control cables 118, 119 and 120. Cable 118 is adapted to operate fuel cock 54, increasing the fuel flow therethrough upon pedal 115 being depressed and, conversely, decreasing the flow therethrough upon pedal 115 being released. Control 119 simultaneously operates air flow control valve 35 so that, in combination with cable 118 and fuel cock 54, both the speed of engine 21 and the volume of compressed air generated by compressors 22 and 23 are controlled by accelerator pedal 115. The third control 120 is adapted to operate two-way valve 38 in duct 26 in such a manner that, upon completely releasing pressure on accelerator pedal 115 to permit engine 21 to idle, compressed air passing through duct 26 is directed through by-pass pipe 39, thereby relieving turbine 24 of the driving force from the compressed air directed thereto under normal running conditions.

From the foregoing description it will be obvious that, upon power plant 20 being utilized to drive a motor vehicle, even after the air has been directed through by-pass 39 by means of two-way valve 38, turbine 24 will continue to rotate in a fly-wheel effect and will therefore continue to drive the vehicle wheels.

FIG. 11 illustrates a method by which turbine 24 may be utilized to aid the braking action and, at the same time, may be relieved of excessive strain should it be necessary to brake the vehicle from a high speed.

In this instance, a brake pedal 121 is supported by a hanging rod 122 and, as is conventional practice, is adapted to move arcuately forwardly upon the brakes being applied. A push rod 123 is pivotally attached to rod 122 and is adapted to operate a brake master cylinder 124 direct. Rod 123 is also caused to operate, through appropriate linkwork, a flexible control 128 which may be adapted to operate in conjunction with control 120 to two-way valve 38 in duct 26, or, alternatively, as shown in FIG. 11, may operate a second by-pass valve 125 which, in turn, may open a secondary by-pass duct 126 so that pressure air from duct 26 is fed to turbine 24 even though accelerator pedal 115 is fully released. Simultaneously, a second flexible control 127 is adapted to operate lever 65 of air distribution valve 64 to reverse the direction of flow of air through turbine 24. Turbine 24 is thereby slowed down and subsequently stopped by air pressure applied to the periphery thereof, and in this way the strain of a violent stop through drive shaft 25 is avoided.

By-pass valve 125 or valve 38 may be similarly linked to the reverse selection for the vehicle and effect reverse movement thereof without any further necessity for gears, or the like.

From the foregoing it will be obvious to one skilled in the art that the operating principles behind engine 21 may equally well be applied to drive a wide variety of machinery and may be utilized substantially directly in the driving of pumps such as pneumatic, vacuum or hydraulic pumps.

Another advantage of the present invention lies in the ease with which engine 21 may be accelerated or decelerated, and, the balancing of fuel supplied and work load as described causing engine 21 to run smoothly at all times.

Furthermore, the operation of engine 21 may be compared to that of a plurality of two stroke engines having extremely good scavenging properties due to the pressure at which the fuel air mixture is injected into the cylinders, this being the equivalent of supercharging as applied to other engines. It should also be noted that engine 21 operates at its maximum efficiency throughout, due to the fact that a known, metered amount of fuel air mixture enters each combustion chamber and is adapted to provide thereby a volume equal to a full charge under static conditions. This fact, therefore, provides engine 21 with substantially 100% volumetric efficiency.

Yet another advantage of the present invention lies in the fact that the kinetic energy imparted to the pistons during the power strokes thereof is applied directly in compressing the next charge to be ignited without any friction or lost movement which is normal to a conventional crankshaft engine.

It should also be noted that, although not specifically stated, suitable lubrication may be provided for the few moving parts embodied in power plant 20 in any appropriate conventional manner.

Further to FIGS. 1 and 2, an adjustable pressure relief valve may be located additionally in each branch duct 26*a* joining main air pressure duct 26 to ensure pressure equalizing within all of said branch ducts which again is an aid to synchronization.

The general design of the individual parts of the invention as explained above may be varied according to the requirements in regards to manufacture and production thereof while still remaining within the spirit and principle of the invention without prejudicing the novelty thereof.

The embodiments of this invention in which an exclusive property or privilege is claimed are defined as follows:

1. A free piston engine including a cylinder having a plurality of spaced apart exhaust ports therein and means for the admission thereto of air and fuel; a plurality of pistons operable within said cylinder and piston rods extending outwardly from said pistons, said pistons reciprocating within said cylinder compressing said fuel and air at opposite ends of said cylinder to the point of compression ignition and moving inwardly of said cylinder to compress a further quantity of said fuel and air mixture therebetween at substantially the center of said cylinder to a point of compression ignition; and said exhaust ports permitting burned gases from said ends of said cylinder to evacuate said cylinder during the compression of said fuel and air mixture in the center of said cylinder, and said exhaust ports permitting evacuation of burned gases from the center of said cylinder upon said pistons compressing said fuel and air mixture at said ends of said cylinder.

2. A free piston engine as defined in claim 1 in which said means for admission of air and fuel includes a plurality of cylinder charging valves; compressed air passing through said charging valves into said cylinder; venturi means within each said charging valves metering the flow of said compressed air into said cylinder, fuel supply means connected to said charging valves; and fuel jet means within each said charging valves operable by said compressed air flow for the emulsification and mixing of said fuel throughout said compressed air.

3. A free piston engine as defined in claim 2 in which each said charging valves include a resiliently loaded fuel check valve within said fuel supply means; said check valve closing off said fuel supply upon the cessation of flow of said compressed air.

4. A free piston engine as defined in claim 3 in which each said charging valve includes a resiliently loaded poppet valve permitting flow of said compressed air and fuel into said cylinder upon a lower pressure existing in said cylinder adjacent said poppet valve and closing said cylinder charging valve upon a pressure substantially equalling or exceeding the pressure of said compressed air being engendered within said cylinder adjacent said poppet valve.

5. A free piston engine including a cylinder member having two spaced apart exhaust ports through the walls thereof; exhaust manifold means and exhaust pipes interconnecting said ports with said manifold; end walls oppositely located within said cylinder having guide holes formed centrally therethrough; two pistons reciprocatingly received within said cylinder; a piston rod integral with each said piston extending outwardly therefrom coaxially with said cylinder; one of said piston rods extending through each of said holes in said end walls of said cylinder; end combustion chambers formed between said pistons and said end walls and a center combustion chamber formed between said pistons within said cylinder; at least one cylinder charging valve for the admission of a compressed air and fuel mixture to each of said combustion chambers; compressed air supply means connected to each of said charging valves and fuel supply means to each of said charging valves; said exhaust ports being located midway between said center chamber and said end chambers; and said pistons moving outwardly from said center chamber having substantially unrestricted movement until having covered and moved beyond said exhaust ports into said end chambers; said pistons having similarly unrestricted movement upon moving inwardly from said end chambers until having covered and moved beyond said exhaust ports into said center chamber; and means for the conversion of the reciprocal motion of said pistons into useful work.

6. A free piston engine as defined in claim 5; pressure balance means interconnecting said end cylinders for synchronizing the operation of said pistons within said cylinder.

7. A free piston engine as defined in claim 6 including governor means for the control of the speed of said engine operable by the power output of said engine.

8. A free piston engine as defined in claim 1 including high pressure air starting means; first valve means for the isolation of said compressed air; second valve means for the direction of said high pressure air through said air charging valves; and switch means for the alternate

distribution of said high pressure air between said center chamber and said end chambers.

9. A free piston engine as defined in claim 8 having cooling means and lubrication means therefor.

10. A free piston engine as defined in claim 5 in which said means for the conversion of the reciprocal motion of said pistons into useful work includes a double acting air compressor operable by each of said piston rods, said air compressors generating compressed air for the operation of a turbine motor and engine accessories and for the supply of compressed air to said cylinder; tank means for the storage of a portion of said compressed air; and air booster pump means operable by said engine for the raising of the pressure within said tank to a higher pressure for starting said engine.

11. A free piston engine as defined in claim 10 including a variable position cock controlling the flow of said fuel to said engine; control means for the selective positioning of said cock and lever means for the operation of said control means; movement of said lever thereby controlling fuel supply to said engine and controlling the speed of operation thereof.

12. A free piston engine as defined in claim 10 including compressor control means governing the flow of air supplying said compressors, said compressor control means operable in combination with said fuel control means to relieve compressor load from said engine upon said engine being selected to operate at low speeds.

13. A free piston engine as defined in claim 5 including high pressure air starting means; first valve means for the isolation of said compressed air; second valve means for the direction of said high pressure air through said air charging valves; and switch means for the alternate distribution of said high pressure air between said center chamber and said end chambers.

14. A free piston engine as defined in claim 13 having cooling means and lubrication means therefor.

No references cited.