Dec. 10, 1957 R. P. RAMSEY ET AL 2,815,641

STARTING SYSTEM FOR FREE PISTON ENGINES

Filed Jan. 16, 1952 3 Sheets-Sheet 1

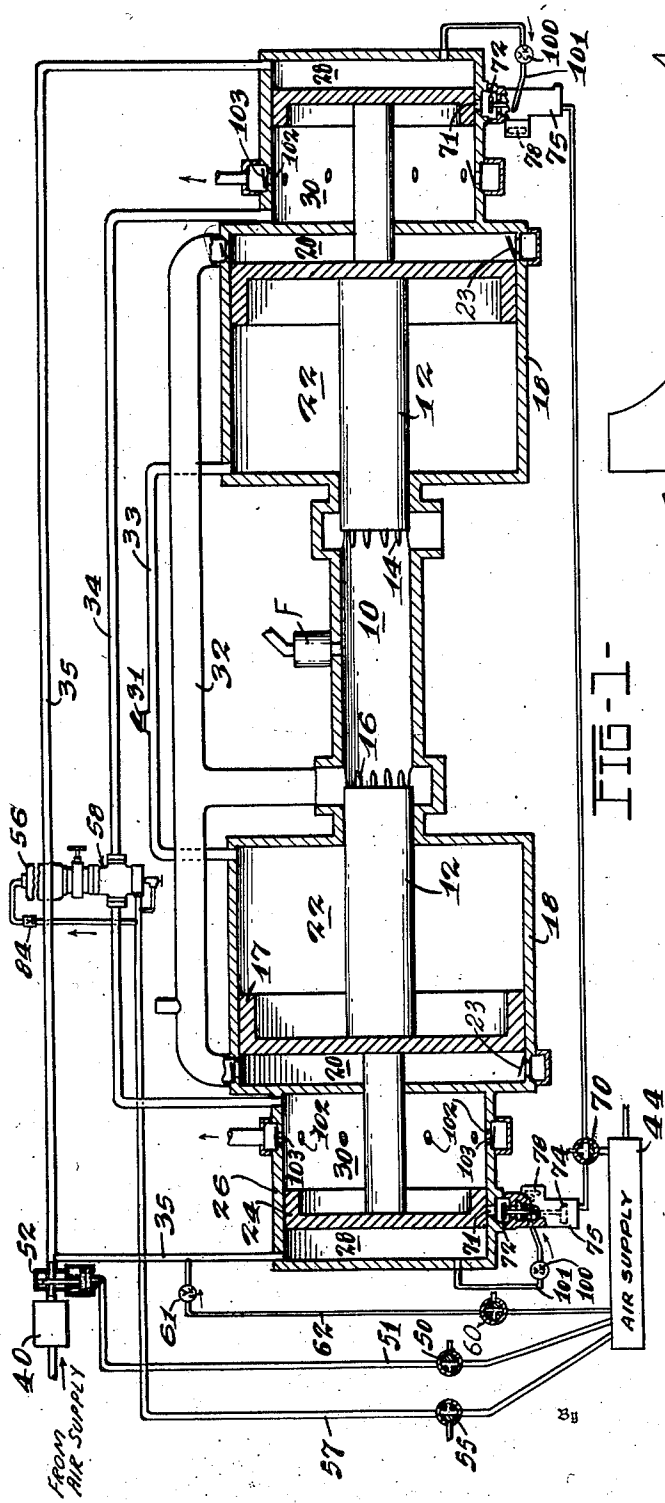


FIG-1-

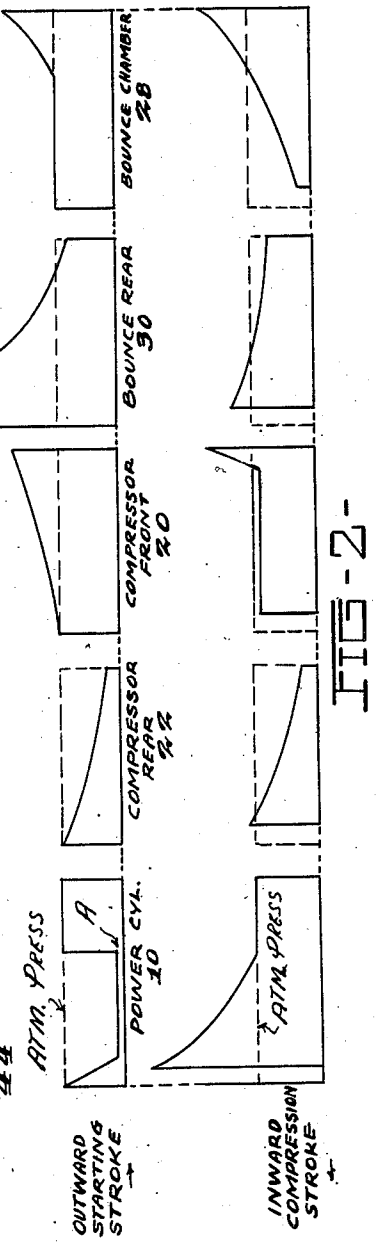


FIG-2-

Inventors:
ROBERT P. RAMSEY,
WILLARD A. MORAIN.

By

Attorneys

Dec. 10, 1957 R. P. RAMSEY ET AL 2,815,641

STARTING SYSTEM FOR FREE PISTON ENGINES

Filed Jan. 16, 1952 3 Sheets-Sheet 2

FIG-4-

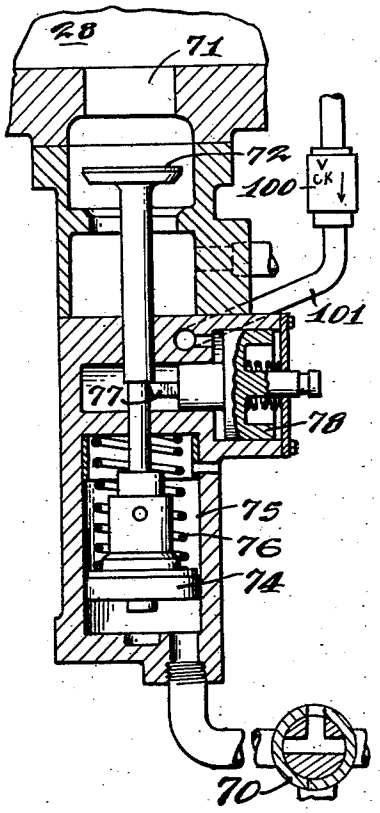
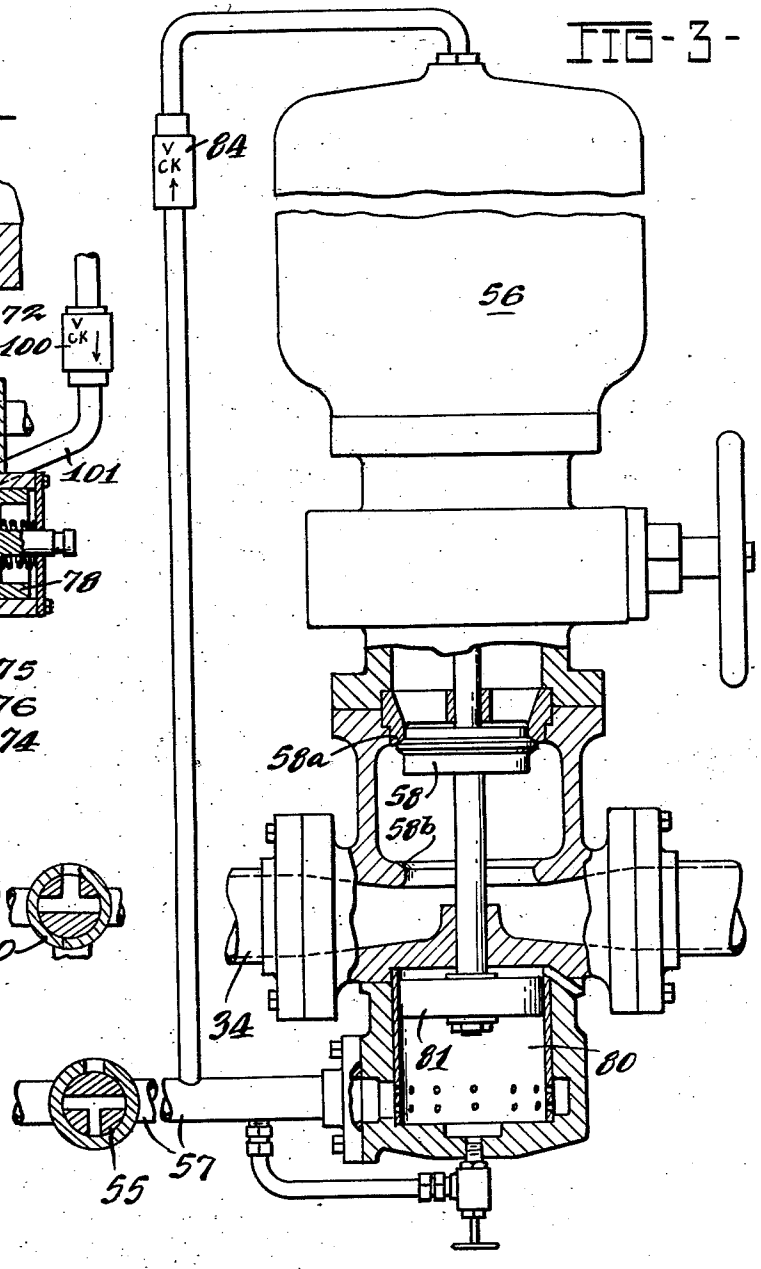


FIG-3-



Inventors:
ROBERT P. RAMSEY,
WILLARD A. MORAIN.

By

Attorneys

Dec. 10, 1957 R. P. RAMSEY ET AL 2,815,641

STARTING SYSTEM FOR FREE PISTON ENGINES

Filed Jan. 16, 1952 3 Sheets-Sheet 3

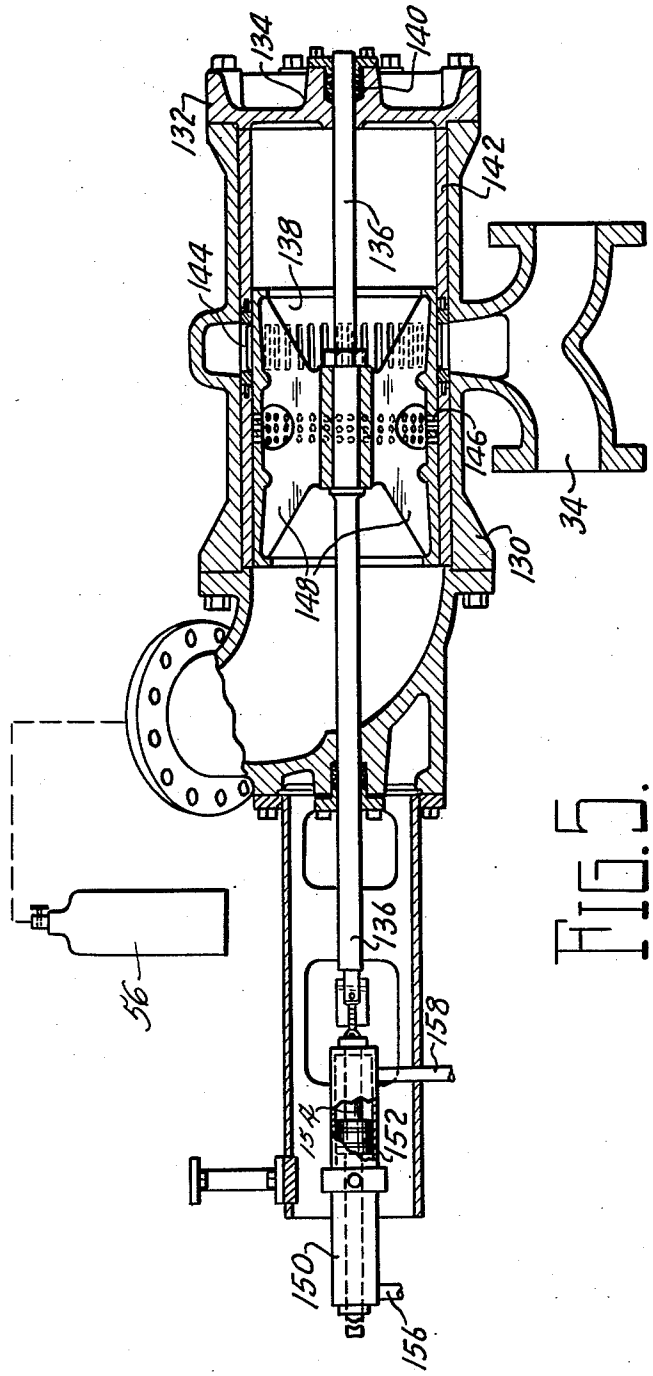


FIG. 3.

INVENTORS
ROBERT P. RAMSEY
WILLARD A. MORAIN
By Owen & Owen
ATTORNEYS

United States Patent Office 2,815,641 Patented Dec. 10, 1957

2,815,641

STARTING SYSTEM FOR FREE PISTON ENGINES

Robert P. Ramsey and Willard A. Morain, Mount Vernon, Ohio, assignors to The Cooper-Bessemer Corporation, Mount Vernon, Ohio, a corporation of Ohio

Application January 16, 1952, Serial No. 266,764

7 Claims. (Cl. 60—14)

This invention relates to starting of free piston engines, and has for its primary object the provision of a starting system in which the pressures existing in the several cylinders at the end of the starting stroke are at, or very close to, the pressures to be expected during normal running of the engine.

Free piston engines in which air is relied upon to return the pistons to the center or compression position have, in the past, been started by injecting a charge of air behind the pistons in the "bounce" cylinders to drive them together. The bounce or energy accumulator cylinders normally run with a very closely controlled increase and decrease in pressure so that the quantity of air trapped in the cylinders must be closely controlled. It almost invariably happens that the quantity of air required to drive the pistons on a starting stroke differs considerably from the quantity desirable for running, so that the quantity of the starting air must be changed rapidly at the end of the starting stroke, leaving a precisely predetermined quantity in the cylinder. This, in some types of engines, is difficult to accomplish.

Certain free piston engines are of the type in which all of the energy developed during an outward stroke of the pistons is accumulated behind the compressor pistons and returned to the cycle as work in a compressor cylinder, and work in compressing the air in the power cylinder, during the inward stroke. It has been heretofore proposed to start engines of this type by controlling exactly the pressure and volume of the starting air by segregating the air in a separate chamber, and subsequently opening this chamber to the rear end of the compressor cylinders. This procedure usually requires that the pistons be located properly, prior to starting, at some intermediate position between the extremities of a normal stroke. One object of the present invention is to avoid the necessity of precise piston positioning, the pistons being permitted to move to the full inward position.

Other types of free piston engines extract the work of compressing air from the cycle during the outward stroke of the pistons. Such engines use a separate bounce cylinder. It has been proposed to inject the starting air into the bounce cylinders of these engines and to remove a part of the air when the pistons reach the innermost position. There is, thus, a necessity for precise timing of the air removing valves which must be closed during a very short interval when the pistons are traveling at high speed, as well as the usual accurate control of the pressure and volume of the starting air.

It will thus be seen that the previously known starting systems are such that a proper energy balance in the engine at the end of the starting stroke is difficult to obtain. The present invention comprises means for introducing starting air to force the pistons apart, rather than together, for the initial stroke. Such a departure from the known practice makes it possible to eliminate precise timing of unloading valves, and greatly facilitates the establishment of a properly balanced system as well as giving other advantages hereinafter explained.

In the accompanying drawings, Fig. 1 is a diagrammatic longitudinal sectional view of a free piston engine having a starting system in accordance with the present invention; Fig. 2 is a group of pressure curves for the several chambers in which pressure variations occur; Fig. 3 is a somewhat diagrammatic view, partly in section of a suitable starting bottle and control valve; Fig. 4 is a central vertical section of a vent control valve, shown somewhat diagrammatically, and Fig. 5 is a central sectional view of a modified, air operated, air feed valve.

Referring to the drawings, and particularly Fig. 1, the free piston engine there diagrammatically disclosed includes opposed piston and cylinders symmetrical with respect to the center so that only one need be described. A center power cylinder **10** is provided in which a power piston **12** reciprocates, the piston **12** controlling the engine exhaust ports **14** in the usual manner. The opposed piston of the set controls air inlet ports **16**.

The power piston is made integral with or connected to a compressor piston **17** operating in a compressor cylinder **18** and dividing that cylinder into a "compressor front" chamber **20** and a "compressor rear" chamber **22**.

Extending rearwardly of the compressor piston is a third piston section **24** which is the energy accumulating or bounce piston. This piston works in a bounce cylinder **26** and divides the cylinder into a "bounce front" chamber **28** and a "bounce rear" chamber **30**.

A suitable scavenging connection **32** connects the compressor space **20** and the inlet ports in the power cylinder. Pressure equalizing line **33** connects the compressor rear chambers **22** on each side of the center of the engine, an equalizing line **34** connects the bounce rear spaces **30**, and a third equalizing line **35** connects the bounce front chambers **28** which will be hereafter referred to simply as the bounce chambers.

The engine is provided with a pressure regulating device **40** to control the air pressure in the bounce chambers **28** to maintain the energy balance during variations in load, but this unit forms no part of the present invention, so that it is indicated only as a box in the equalizing line **35** that connects the controlled chambers.

The starting system of the present invention takes its air from any suitable source, designated **44**. The several valves by which the flow of air from the source is regulated are shown as separate, unrelated units, although it should be expressly understood that the valves may be grouped for easy sequential operation in a manner well known in the art. As the valves by which air is introduced into the system are, in themselves, old and well known, they are not shown or described in detail. In practice the valves are grouped for operation by a single device such as a hand wheel which has certain predetermined positions, six in the present instance.

Valve **50** is a three-way valve having feed and vent positions. The valve in its feed position operates to conduct air from supply source **44** through pipe **51** to a shut-off valve **52** ahead of the bounce pressure regulator **40** to render the regulator temporarily inoperative. The regulator is so arranged that it operates to maintain a predetermined pressure in the bounce chambers **28** and must, therefore, be taken out of operation during any starting cycle in which the pressure in the bounce chambers is considerably different than normal during most of the starting period.

In the execution of the invention shown in the drawings, a second three-way supply valve **55** is connected between the supply source **44** and a starting air bottle **56**, the valve being interposed in a line **57**. The starting air bottle is charged to a predetermined pressure and preferably has a predetermined volume. It is held out of communication with the engine by a quick opening valve **58** which is pneumatically operated as hereinafter de-

scribed. If desired, the three-way valve 55 may be eliminated and the bottle 56 charged continuously through a small, non-return valve. It is only necessary that bottle 56 contain enough air at the proper pressure to effect a start whenever required.

A third valve is indicated at 60. This valve operates to supply air through a check valve 61 to the bounce chamber equalizing line 35. The introduction of air into the bounce chambers 28 continues until the pistons reach their innermost or center position at which time valve 60 can be closed, discontinuing the introduction of air into the bounce chambers.

A vent control valve for the bounce chambers is provided which is designated 70 and is operated next in the sequence. In the feed position of this valve, inwardly opening vent valves 72, associated with vent ports 71 provided in the periphery of the accumulating chambers 28 are opened, these valves being connected at their stems with pistons 74 operating in cylinders 75 against springs 76. So long as pressure is maintained on the lower face of pistons 74 the vent valves will remain open. A latch comprising a pneumatically operated bar 77 is provided adjacent each of the vent valves 72. The latches are urged into engagement with the stems of valves 72 and are removed therefrom by the introduction of air ahead of pistons 78 to which the latch bars are connected.

It will be seen that by sequentially operating valves 50, 55, 60 and 70 that the bounce pressure regulator 40 has been temporarily rendered ineffective, the starting bottle 56 has been charged, the pistons have been moved to their center positions and chambers 28 have been vented. Valve 70 may then be moved to vent position removing the air pressure from the face of the vent valve control pistons 74, but the valves themselves will not close since the latch bars 77 operate to prevent this movement.

At the same time that the starting bottle 56 is charged by opening valve 55 thus introducing air into line 57, air passes into the end of a valve control cylinder 80 and behind piston 81 as can be seen in Fig. 3. A check valve 84 is interposed in the branch of line 57 between the three-way charging valve 55 and the starting bottle 56. Pressure of air behind piston 81 maintains valve 58 closed until cylinder 80 is vented by moving valve 55 to its vent position.

When the pistons have been moved to their center position and the accumulator cylinders vented by opening vent valves 72, the starting operation is initiated by rotating valve 55 to vent position and permitting the air in cylinder 80 to escape. Piston 81 thus has its rear face at substantially atmospheric pressure while the head of the valve 58 to which it is connected is subject to the full pressure of the air in starting bottle 56. This causes the quick opening valve 58 to move rapidly outwardly and to permit the starting air in the bottle to expand into equalizer conduit 34 which connects the "bounce rear" spaces at each end of the engine. Valve 58 may be shrouded at the top and bottom so that the passages which it controls are opened and closed gradually. It will be seen that before the shroud of valve 58 leaves seat 58*a* the valve body has already attained a considerable velocity so that the period over which the valve is fully opened is relatively short. When the valve 58 seats on seat 58*b* the flow is first rapidly shut off by the protruding shroud and the valve has a tendency to seat easily and without exerting destructive forces on the valve seat. The effect of the shroud is to effectively open and close valve 58 at high speed even though the acceleration and deceleration of the valve body are kept low for structural reasons. The damping action of the shroud on the valve head can be augmented by fitting piston 81 relatively closely in cylinder 80 and spacing the air connection to the cylinder a short distance from the end of the cylinder. This causes a small quantity of air to be trapped behind the piston 81 at the end of its movement which air can act as a cushion for the valve body 58.

Air into the bounce rear spaces 30 starts the pistons on their first outward stroke. The vent valves 72 being open, the air in the bounce chambers 28 remains at substantially atmospheric pressure until ports 71 controlled by vent valves 72 are covered by the pistons 24 at which time the air pressure in the bounce chambers begins to rise. The increase in the pressure in the bounce chambers operates through a check valve 100 and line 101 to the front face of the pneumatically actuated latches 77 causing the latches to be withdrawn and permitting the vent valves 72 to close. It will be seen that the time of closure of valves 72 is not critical and that this closure can take place at any time in the interval when the ports 71 are first covered and when these ports are uncovered by the pistons on their next inward stroke.

The pressure of the starting air from bottle 56, after passing valve 58 into the equalizing line 34 to bounce rear spaces 30, exerts its force on the rear faces of the bounce pistons only for the time required to accelerate the pistons to the proper velocity to store therein the kinetic energy required for the remainder of the outward stroke. The starting air may, at this time be vented from the bounce rear spaces 30, and ports 102 controlled by outwardly opening check valves 103 are provided in the walls of the chambers 30 for this purpose. These valves may be of any suitable type, but are preferably reed valves hinged to swing outwardly a predetermined distance from their ports. The pressure in the cylinder will drop rapidly, and should reach atmospheric pressure at about the end of the outward stroke of the pistons, and prior to the time the pistons commence to return.

The operation of the starting system may best be followed from the pressure-stroke diagrams comprising Fig. 2. The top line of diagrams corresponds to the pressures existing in the several chambers on the right-hand side of the engine shown in the drawing. This first diagram represents the pressures existing in the power cylinder and indicates that the pressure is atmospheric in the beginning of the first outward stroke or starting stroke. A suction is created in the power cylinder which reaches a given value depending on the leakage past the rings of the piston and remains at that value until point A is reached at which time one of the pistons uncovers the exhaust ports 14 which immediately relieves the vacuum in the power cylinder. The power cylinder then maintains a substantially atmospheric pressure until the completion of the outward starting stroke.

The second diagram indicates the conditions existing in the chamber at the rear of the compressor piston indicated at 22. This chamber begins its outward stroke at atmospheric pressure and draws a gradually increasing vacuum during the entire outward stroke so that the pressure declines on a substantially logarithmic curve.

The pressure in the compressor "front" space 20 is next indicated, and it will be seen that this chamber shows a gradual increase in pressure due to the movement of the compressor piston in a direction tending to decrease the size of the space in which the air is disposed, reaching some predetermined value above atmospheric pressure at the end of the outward starting stroke. The value reached at the end of the stroke is somewhat above atmospheric pressure and there is some flow from the compressor cylinder 20 into the scavenging header 32 and into the power cylinder. It is found that the power cylinder has an appreciable pressure at the conclusion of the first outward stroke, due largely to the inability of the air to transfer instantaneously to the cylinder 10 and out the exhaust ports 14.

The bounce rear chamber is the chamber into which air is injected through equalizer pipe 34 from the starting

bottle 56. Thus this chamber commences the outward stroke at a very high pressure corresponding to the pressure of the expanded air from the starting bottle. This pressure is maintained until ports 102 are uncovered by the outwardly traveling bounce pistons. The air in this chamber then expands down to atmospheric pressure by exhausting through the check valves 103 at a rate determined by the size of the passages, by the resistance of the check valves and the configuration of the elements which the air must pass in escaping. The energy imparted to the pistons by the expansion indicated and by the stored kinetic energy is sufficient to carry out the entire starting stroke and may be increased or decreased at the selection of the designer. The check valves 103 operate to maintain atmospheric pressure in the bounce rear spaces at the position selected for the ports during normal operation of the machine with normal variations above and below this pressure as the volume of the spaces changes.

The pressure in the bounce chambers is indicated by the last diagram in the upper line and it will be seen that the air in these chambers stays at substantially atmospheric pressure until such time as the ports 71 are covered by the bounce piston in its outward stroke. Thereafter, the pressure in the now-closed bounce spaces rises rapidly. Valves 72 are open during the outward stroke of the bounce piston and are closed by the pressure increase in the bounce chambers 28, air being displaced through check valve 100 and line 101 to act on the front face of piston 78 and withdrawing the latch bar 77 from beneath the shoulder on the stem of valve 72. Thereafter the valves 72 remain closed during normal running. There is ample time for valves 72 to close.

The inward compression stroke which is brought about by the outward stroke above described is the result largely of the energy stored in bounce chambers 28 and may be followed from the second line of diagrams which comprise Fig. 2.

The energy in the bounce chamber 28 expands down from the peak reached at the outermost position of the pistons to a pressure less than atmospheric when the pistons have completed their inward stroke. This expansion is indicated by the curved graph line at the lower right of Fig. 2. A small amount of energy is expanded in the bounce rear space 30 as indicated, this chamber maintaining atmospheric pressure for most of the inward travel but rising at the inner end of the stroke when ports at 102 are covered by the bounce piston.

A slight contribution of energy from the compressor cylinder 20 results from the re-expansion of air trapped in the end of this cylinder at the end of the first outer stroke and returned to the cycle on the first inward stroke. Thereafter, the chamber 20 is at somewhat less than atmospheric pressure since air is entering the compressor cylinder through its inlet valves designated 23 in Fig. 1.

The compressor rear operates to return energy to the cycle since the vacuum that has existed in this space at the end of the outward starting stroke is relieved and the chamber comes up to slightly more than atmospheric pressure at the end of the stroke. These chambers may conveniently be vented by an outwardly opening check valve 31 in the equalizing line 33 which connects them.

As above noted the power cylinder commences the first compression stroke with a positive pressure, in the order of 2.5 lbs., existing therein by reason of the inertia of the air column supplied during the starting stroke. This pressure is increased after the exhaust and scavenging ports are closed on the usual compression curve and reaches a peak when the pistons are at their closest inner position. Substantially all of the energy that was stored in the bounce chambers 28 is expended in increasing the pressure in the power cylinder and the pressure therein reaches a sufficient value to cause compression ignition of fuel injected into the cylinders if the engine is operated on a diesel cycle or to compress a charge of gas for spark ignition if the engine is operated on gas on an Otto cycle.

A fuel injector F has been diagrammatically indicated in Fig. 1.

As above noted, valves 72 are closed at any time during the interval when the ports 71 are closed by the bounce pistons moving outwardly on the starting stroke and when these same ports are uncovered by the bounce pistons moving inwardly on the compression stroke. There is thus no critical time when the valves are required to be closed since this interval in the cycle is relatively long.

After the engine has completed its first inward compression stroke as indicated in Fig. 2 all of the cylinders and chambers are at the proper operating pressure and the engine is in idle running condition. As soon as is practicable, the bounce pressure regulator 40 is reinstated by removing the disabling element therefrom and permitting the governor to readjust the pressures in the bounce chambers 28 for any change in load. There will be some increase in pressure in the compressor cylinder 20 when the engine is operating under load since the engine exhausts at well above atmospheric pressure, depending on the load to which it is subjected, and the compression pressure in the chambers 20 must be greater than the exhaust pressure from the power cylinder for proper scavenging. This effect is, of course, compensated for by the bounce governor operating in a known manner.

An alternate form of control valve for introducing a predetermined and limited quantity of air from a storage bottle to the equalizer pipe 34 and thus into the "bounce rear" chambers is shown in Fig. 5. This valve operates on the principle that relatively unrestricted communication is desired between the storage bottle and the equalizer pipe 34 for a limited period of time, which period can be increased or decreased depending on the velocity imparted to a control element, and the volume of starting air will be directly related to the time during which the storage bottle is allowed to communicate with the conduit that passes air to the engine. In the construction shown, the valve comprises a casing 130 closed at one end by a head 132 which has a central guiding boss 134 for operating stem 136 to which a control piston 138 is connected. Appropriate packing 140 is provided for stem 136 in boss 134 to prevent the leakage of high pressure starting air. A cylinder liner 142 is disposed within body 130 and has a plurality of large and relatively unrestricted ports 144 intermediate its length. The interior of the cylinder formed by liner 142 is in open and unrestricted communication with the air storage bottle indicated diagrammatically at 56. Piston 138 has a relatively long skirt or outer surface and is provided with a series of holes 146 in its periphery. The piston skirt is supported by a series of spaced webs 148 which connect the periphery of the piston to the actuating rod 136. The piston fits sufficiently tightly in cylinder 142 that so long as the holes 146 are out of registry with ports 144 no air passes into the ports into the equalizer pipe 34. However, when ports 146 are brought into coincidence with the peripheral series of ports 144 air passes freely from the interior of the cylinder through holes 146, ports 144 and into equalizer pipe 34.

Any suitable means may be used to reciprocate the piston 138 and thus bring its peripheral holes into registry with the ports. As diagrammatically indicated in Fig. 5 the actuator preferably takes the form of a small pneumatic cylinder 150 in which a piston 152 is mounted and attached to a piston rod 154 which is detachably connected by any suitable device to piston rod 136. Cylinder 150 may be made double acting, that is air may be introduced into either end and controlled exhaust provided at the opposite end thus furnishing very close governing of the speed of movement of the actuating piston. The air supply and discharge pipes are indicated at 156 and 158.

As piston 138 is moved longitudinally, its ports 146 pass over ports 144 in the cylinder wall, and during the time required for this passage the source of air pres-

sure, whether it be storage bottle **56** or its equivalent, is in direct communication with equalizer pipe **34** and thus with the chambers in the engine which receive the starting air. As the interval is made longer or shorter by slowing down or speeding up the rate of travel of piston **138** the quantity of starting air can be varied. Any suitable automatic or manual valve arrangement may be used to control the supply to pipes **156** and **158** for this purpose.

It will be appreciated that the invention has been diagrammatically indicated in the drawing and no attempt has been made to indicate the proper relative size of the ports or their mechanical construction since, for the most part, the valves are conventional units except for the vent valve **72** and its associated parts, the quick opening valve **58** and its operator and the air metering valve formed by piston **138**. These have, therefore, been shown in more detail for a more complete understanding of the invention.

What we claim is:

1. A starting means for rapidly stabilizing a free piston engine having a power cylinder, a compressor cylinder and a bounce cylinder, connected power, compressor and bounce pistons in said cylinders, the piston in said bounce cylinder dividing said cylinder into front and rear chambers, said starting means comprising a source of air under pressure, means to connect said source of air to one of said cylinders to charge said cylinder and to position said pistons near the inner end of their stroke, means to trap air at predetermined pressure in the front chamber of said bounce cylinder, valve means to vent said charged cylinder operable after the pistons have been positioned, means to introduce starting air at high pressure and in predetermined volume into one of said cylinders and against the rear face of that one of said pistons in said one cylinder to drive said connected pistons outwardly against air in said bounce cylinder, and means to close said vent valve means operable during said outward stroke.

2. A starting means in accordance with claim 1 in which said valve means to vent said charged cylinder comprises a plurality of valves in a peripheral series in the wall of the cylinder short of the end thereof, and said means to close said vent valves is actuated in the interval between the time when the adjacent one of said connected pistons passes said valves in a covering and an uncovering direction.

3. A starting means in accordance with claim 2 in which said means to close said vent valves are actuated by air from said bounce cylinder, said air being compressed to operating pressure by outward movement of said connected pistons.

4. A starting means in accordance with claim 1, and means to vent the cylinder into which starting air is introduced.

5. A starting means in accordance with claim 4 in which said vent means comprises piston controlled ports in the wall of said cylinder into which starting air is introduced.

6. A starting means in accordance with claim 5, and outwardly opening check valves associated with said ports, whereby the pressure in said cylinder is reduced to atmospheric pressure at or prior to the end of said outward stroke and maintained substantially at said pressure thereafter.

7. A starting means for rapidly stabilizing a free piston engine having a power cylinder, a compressor cylinder and a bounce cylinder, connected power, compressor and bounce pistons in said cylinders, the piston in said bounce cylinder dividing said cylinder into front and rear chambers, and the piston in said compressor cylinder dividing said compressor cylinder into front and rear chambers, said starting means comprising a source of air under pressure, means to position said pistons near the inner end of their stroke with the power piston at substantially the position corresponding to maximum compression, means to trap air at predetermined pressure in the front chamber of said bounce cylinders when said pistons are so positioned, and means to introduce starting air from said source at high pressure and in predetermined volume into one of said cylinders and against the rear face of that one of said pistons disposed in said one cylinder to drive said connected pistons outwardly against said air trapped in said bounce cylinder, whereby the energy stored in said trapped air at the end of said outward stroke causes a substantially normal return stroke of said pistons to the inner position.

References Cited in the file of this patent

UNITED STATES PATENTS

2,215,326	Janicke	Sept. 17, 1940
2,423,720	Müllejans et al.	July 8, 1947
2,434,778	Welsh	Jan. 20, 1948
2,434,877	Welsh	Jan. 20, 1948
2,439,482	Meitzler	Apr. 13, 1948
2,600,251	Lewis et al.	June 10, 1952