June 10, 1952 F. M. LEWIS ET AL 2,600,251

STARTER FOR FREE PISTON ENGINES

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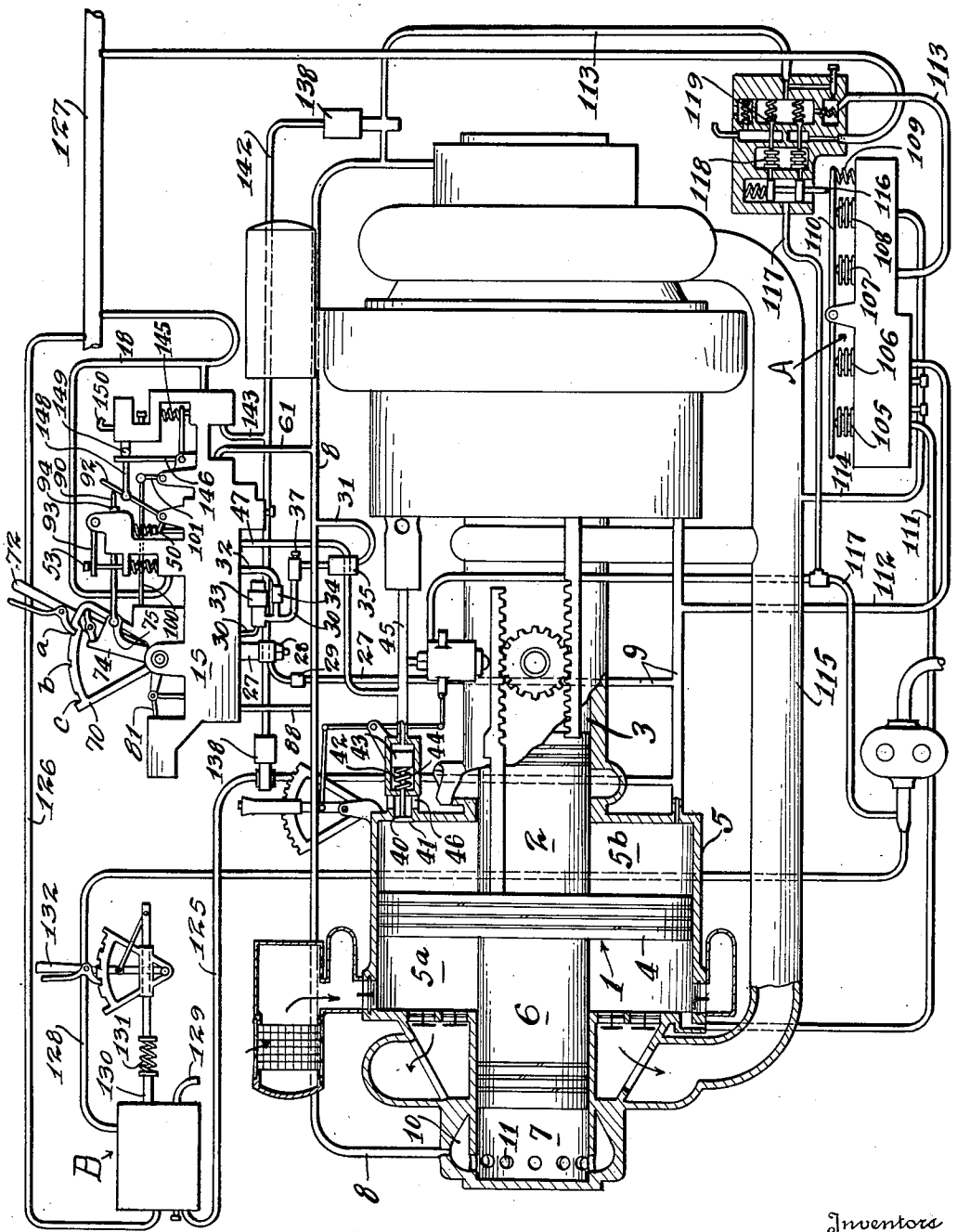

FIG-1-

Inventors
FRANK M. LEWIS
WILLARD A. MORAIN
By Owen & Owen
Attorneys

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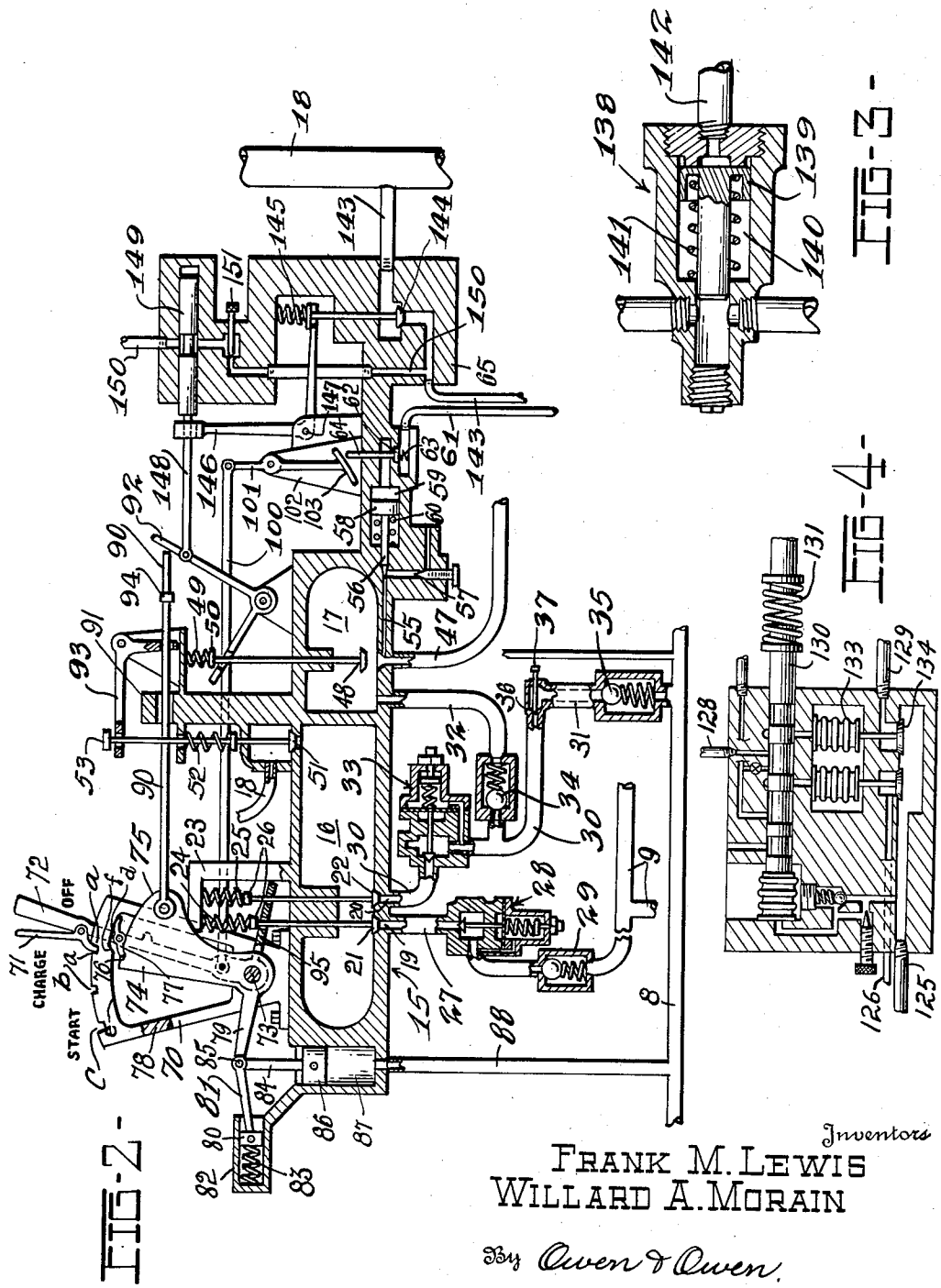

FIG-2-

FIG-3-

FIG-4-

Inventors
FRANK M. LEWIS
WILLARD A. MORAIN

By Owen & Owen

Attorneys.

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STARTER FOR FREE PISTON ENGINES

Frank M. Lewis, Weston, Mass., and Willard A. Morain, Hamilton, Ohio, assignors, by mesne assignments, to Baldwin-Lima-Hamilton Corporation, a corporation of Pennsylvania

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25 Claims. (Cl. 60—14)

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This invention relates to engine starters, and particularly to such starters adapted for use in connection with internal combustion engines of the free piston type.

It is necessary in starting such engines to first place the work pistons at their outer terminal positions and then to force them to their inner terminal positions with a velocity substantially comparable to that of the compression stroke in normal running of the engine whereby pressure and temperature of sufficient values may be generated in the combustion chamber to ignite an injected fuel charge after which the engine will operate in the regular way.

The object of the present invention is the provision of a simple, novel and efficient pneumatic starter of the character described, which will meet the mentioned requirements.

The invention is fully described in the following specification, and a preferred embodiment thereof illustrated in the accompanying drawings, in which:

Figure 1 is a central longitudinal sectional view of one end portion of a free piston engine with the starting means embodying the invention associated therewith; Fig. 2 is an enlarged sectional detail of said starting means; Fig. 3 is a sectional view of a suitable isolation valve; and Fig. 4 is a somewhat enlarged central vertical sectional view of one of the governor control valves.

Referring to the drawings, 1 designates more or less diagrammatically one piston set of an internal comubustion free piston engine including opposed piston sets, each set comprising a working piston 2 operating in a chamber 3, an air compressor piston 4 operating in a cylinder 5, and a direct bounce piston 6 operating in a chamber 7. The piston 4 divides the cylinder 5 into an air compressor chamber 5a and a reverse bounce chamber 5b. The two piston sets are forced outward by combustion of charges therebetween in the chamber 3, supplemented by the effect of any pressure in chamber 5b, and are returned to compress charges therebetween by the force of air compressed in the bounce chambers 7, auxiliary spaces 10, and re-expansion of air trapped in clearance of compression chambers 5a during outward movements of the pistons. The two direct bounce auxiliary chambers 10 are connected by a pressure equalizer pipe 8 while the two reverse bounce chambers 5b are connected by a pressure equalizer pipe 9. One only of each of the chambers 7 and 5b is shown. The pipe 8 preferably connects at each end with the respective direct bounce chamber 7 through an auxiliary air chamber 10 which communicates with the chamber 7 through a series of side ports 11, and these are spaced from the outer end of the chambers so that they will be closed by the

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pistons 6 when at or near the limit of their outward strokes. These pistons have a sufficiently loose fit in the outer end of the chambers 7 so that when the ports are closed by the pistons the air pressure in the auxiliary chambers 10 will be permitted to slowly leak around the ends of the pistons and to enter the free spaces provided between the ends of the pistons and the ends of the chambers 7.

The starter means embodying the present invention and which operates in connection with the above-noted chamber arrangement and connecting pipes includes a body 15 having a high pressure air storage chamber 16 (Fig. 2) and a separate limited pressure air charge chamber 17 therein, with the former in connection with a suitable source of air pressure supply through a passage 18. The chamber 16 has two discharge outlets 19 and 20 adapted to be closed by inwardly opening valves 21 and 22, respectively, the stems of which project outward from the chamber through a wall thereof and into a casing part 23 where they are respectively engaged by springs 24 and 25 to normally maintain the valves seated. The outer end portion of each valve stem is provided with a head 26 receiving the thrust of its spring. The outlet 19 has connection through a line 27 with the pipe 9 connecting the reverse bounce chambers 5b of the engine, and in this line 27 is disposed a pressure regulator 28 and an outwardly opening check valve 29, so that the air passing through the line 27 from the chamber 16 first has its pressure reduced a predetermined extent by the regulator 28 and then passes through the check valve before entering the pipe 9.

The outlet 20 has a connection through a line 30 and through a branch 31 with the equalizer pipe 8 connecting the direct bounce chambers, and also has connection through a branch 32 with the charge chamber 17, with the opening between the branch 32 and chamber continually open. A pressure regulator 33 is disposed in the line 30, and an outwardly opening check valve 34 is disposed in the branch 32. The branch 31 has an outwardly opening check valve 35 therein, and also between such valve and the pressure regulator 33 is provided a restricted passage 36 controlled by a needle valve 37. It is thus apparent that when the valve 22 is open, the high air pressure in the chamber 16 will pass therefrom through the line 30, where it is reduced the desired extent by the pressure regulator 33, after which it divides, with part passing through the check valve 34 and through the branch 32 to the charge chamber 17, and part passing through the valve controlled branch 31 to the pipe 8. The pressure regulators 28 and 33 may be of any suitable construction as well understood in the art, and need not, therefore, be specifically de-

scribed. These regulators, as is common, are manually controllable to regulate the pressure reduction effected thereby.

Each reverse bounce chamber 5b at its outer end relative to the piston 4 is provided with a plurality of pressure relief ports 40 (one only being shown), and each is normally closed by a valve 41, the stem of which projects into a cylinder 42 and attaches to a piston 43 therein. A spring 44 acts against the piston 43 to normally retain the valve closed and pressure is admitted to the outer end of the cylinder 42 through a line 45 to act against the piston 43 in opposition to the pressure of the spring 44 and effect an inward opening of the valve 41. Between the port 40 and cylinder 42 are provided a plurality of exhaust openings 46 for the release of the air pressure to the atmosphere from the reverse bounce chamber 5b when the valve is open. Pressure is admitted to the line 45 from the charge chamber 17 through a line 47. The inner end of the line 47, or that opening into the chamber 17, is controlled by a valve 48, the stem of which projects through and above the top wall of such chamber where it is acted on by a spring 49 to hold the valve closed. The spring seats against a head or enlargement 50 on the outer end of the valve stem.

The admission of high pressure air to the chamber 16 from the line 18 is controlled by a valve 51, the stem of which projects outwardly from the chamber wall through suitable guides and is acted on by a spring 52 to normally maintain the valve seated. The stems of the valves 48 and 51 are disposed, in the present instance, in parallel relation and adjacent to each other with the stem of the latter valve projecting a greater distance from the body 15 than the other and provided at its outer end with a head or shoulder 53. The stems of the valves 21 and 22 are also disposed in rather close parallel relation with the stem of the valve 21 projecting a less distance from the casing of the body 15 than the other. This relative positioning and length of the valves 21, 22, 48 and 51 are to facilitate operation of the valves by the control means hereinafter described.

A pressure relief passage 55 communicates with the pressure line 47 adjacent to its point of connection with the chamber 17 and this line is controlled by a normally open valve 56 and at the outer side of such valve by a needle valve 57. The valve 56 projects from a plunger 58 operating in a cylinder 59 and is normally held open by the pressure of a spring 60 against such plunger. The cylinder 59, at the outer side of the plunger 58, has communication through line 61 with pipe 8 which connects the direct bounce chambers, so that when a sufficient pressure is present in the line 8 to overcome the compression of the spring 60, such pressure will move the plunger 58 and hold the valve 56 closed if valve 62 is in open position as later described. The line 61 has a normally closed check valve 62 therein which opens outwardly from the cylinder 59 and is normally held closed by a spring 63. This valve has a stem 64 projecting upwardly to exposed position through the portion 65 of the body 15 in which it is mounted, and, in the present instance, it is parallel to the stems of the valves 21, 22, 48 and 51. The purpose of the valve 62 will be later described.

The control means for the valves 21, 22, 48, 51 and 62 will now be described. Mounted in the present instance on top of the body 15 near its left end is a stationary guide sector 70 with which the hand operated catch 71 on a hand lever 72 is adapted to engage to hold the lever in different positions of adjustment relative to the sector. In the present instance, the sector has notches *a*, *b* and *c* with which the catch engages to hold the lever, respectively, in "off," "charge" and "start" positions. The lever is mounted on a shaft 73 for rocking movements lengthwise of the sector, and this shaft also carries an independently rockable arm 74, the outer end of which is provided with an arcuate surface 75 concentric to the shaft axis and having a stop 76 near its rear or left hand end. A spring pressed pawl 77 on the lever 72 rides at one end on the surface 75 and at its other end on an inner surface of the sector 70. This latter surface is divided lengthwise thereof into two arcuate surfaces *d* and *e* that are concentric to the lever axis and are connected by a cam portion *f*. When the lever 72 is being moved from "off" to near its "charge" position, the outer end of the pawl 77 will ride against the surface *d* and cause the arm 74 to move therewith due to engagement of the inner end of the pawl with the shoulder 76. When the lever has nearly reached said charge position, the outer end of the pawl 77 will engage and pass over the cam surface *f*, thereby moving the pawl to disengaged position relative to the shoulder 76 and maintaining such position during movement of the pawl along the surface *e*.

Projecting rearwardly from the inner end of the arm 74 away from its rocking axis is an arm 79 that is pivotally connected at its outer end to a plunger 80 by a link 81, such arm and link forming a toggle connection between the inner end of the arm 74 and the plunger, with such connection upwardly broken or raised from straight or dead center position when the arm 74 is at the limit of its movement to the right. The plunger 80 works in a cylinder 82 and receives the thrust of a coiled compression spring 83 in said cylinder acting inwardly on the toggle link members 79, 81. A rod 84 projects from the pivotal connecting point 85 of the members 79 and 81, substantially at right angles to the line of movement of the plunger 80, and connects at its outer end to a plunger 86 operating in a cylinder 87. The outer end of this cylinder relative to the rod 84 forms an air pressure chamber that has communication through a line 88 with the pipe 8 connecting the direct bounce chambers of the engine. It is apparent that air pressure in the pipe 8 acts through the line 88 against the piston 86 and tends to keep the connection 79, 81, in its upwardly broken position. When the arm 74 has been moved a short distance to the left from the "off" position shown, by a counterclockwise movement of the lever 72 from its "off" position, the toggle connection 79, 81 will have lowered an extent sufficient to move the pivot 85 across and below dead center position so that the plunger 86 will then be quickly moved downward in its cylinder 87 by the downward breaking movement of the toggle connection and under the pressure of the spring 83, thus causing the arm 74 to quickly move independently to the left of the lever 72 to its stop position against the part 78. It will be understood that at this stage in a starting operation there is practically no pressure in the direct bounce chambers 7 and consequently in the line 8 with which the cylinder 87 is connected. It will also be understood that when the direct bounce pressure has increased sufficiently in the chamber 87 to overcome the

enter the pressure responsive means 118 and open valve 119, thereby venting the bounce pressure chamber 7 to the atmosphere.

The reverse bounce pressure governor B has a line 125 in connection with the reverse bounce chambers 5b, a line 126 in connection with a high pressure air supply line 127, a fluid pressure line 128, at present in connection with the fuel feed line of the engine, and a normally closed vent line 129. Line 126 acts only during running of the engine as part of the governing function and forms no part of the starter mechanism. A control valve 130 is moved to the right by pressure in line 125 when pressure in spring 131 is relieved by moving control lever 132 to "stop" position. Pressure in line 125 acts to expand a bellows at the left of valve 130 forcing the latter to the right. This movement of valve 130 admits pressure from line 128 to pressure responsive means 133, which causes opening of relief valve 134 to vent the pressure in reverse bounce pressure line 125. Such venting relieves the pressure from responsive means 106 in governor A and permits movement of lever 110 by spring 109 to effect a venting of the direct bounce chambers 7 through the lines 113 and 8.

It is thus seen that when the engine is stopped, the governor B acts to relieve the reverse bounce pressure and that this in turn acts through governor A to vent the direct bounce chamber pressure. The invention is disclosed in conjunction with these governors since it has been constructed in this manner and the disclosure is thus of preferred form. However, any equivalent pressure sensitive valve arrangement may be used.

In order to make the starting means operative in connection with an engine having such direct and reverse bounce venting means, it is desirable to have an operative connection between the starting and venting means, whereby the two governors are blocked off from the respective direct and reverse bounce chambers during the starting process and are opened thereto as the unit achieves running equilibrium.

To accomplish this the direct bounce pressure line 113 to governor A and the reverse bounce pressure line 125 to governor B are each provided with an isolating or block-off valve 138, shown in detail in Fig. 3. Each of these valves moves across the respective pressure line 125 and 113 and carries a piston 139 operating in a cylinder 140. The valve is normally held open by a spring 141 and is closed by pressure against the outer side of the piston supplied through a line 142. This line connects both valve cylinders and is supplied with pressure from the high pressure air line 18 through a branch 143 extending through a part of the starter body structure 15 (Fig. 2). A valve 144 is acted on by a spring 145 to normally close said branch within said structure and the valve is unseated by movement of a bell crank lever 146. This lever is fulcrumed at 147 and has one arm engaging the valve stem and its other arm engaging a rod 148 attached to and operable by movements of the upright arm of the lever 92. This attachment is such that upon a rearward or counterclockwise movement of said lever under the action of the spring 49, and when the rod 90 is moved to the left, the lever 146 is moved to lift the valve 144 from its seat and open the line 143. The rod 148 also controls a vent valve 149 to close a vent passage 150 when the rod is moved to the left and to open such passage when the rod is in its right hand position. The passage 150 leads to the atmosphere from the line 143 at a side of the valve 140 opposed to the air pressure supply source. The vent 150 is so restricted by the throttling needle valve 151 as to retard the engagement of the governors A and B until after the unit achieves running equilibrium.

A brief description of the operation of the starter means is as follows: Presuming that the pressures in the bounce chambers 7 and connected auxiliary chambers 10 have been vented through the relief passage in governor A when the engine was last stopped, the operator sets the fuel feed for a running condition slightly greater than idling and also sets the control 132 for the governor B so as to tension the spring 131 to provide for proper reverse bounce effect which will be achieved by the starting conditions. This moves the valve 130 to the left permitting a closing of the relief valve 134 so that the vent from the reverse bounce chambers is closed. However, the vent from the chambers 7 and 10 is still open through the governor A. The operator then moves the starter control lever 72 from the "off" to the "charge" position, that is, from the *a* to the *b* notches in the sector 70. The rocker arm 74 moves with the lever in this movement due to the engagement of the pawl 77 with said arm until the pivot 85 of the toggle 79, 81, has been moved past dead center position, whereupon the spring 83 will act to quickly move the rocker arm to the limit of its rearward or counterclockwise movement. This movement of the rocker arm closes valve 48 and opens the valve 51, the latter admitting high pressure air to the chamber 16 from lines 18 and 127. At the same time, when the lever 72 is near its "charge" position, its arm 95 will engage the head 26 and open the valve 21. This permits high pressure air to pass from chamber 16 through the valve controlled line 27 to the reverse bounce chambers 5b to force the engine pistons to the limit of their outward movements. The movement of the control lever 72 to "charge" position moves the pawl 77 to released position relative to the shoulder 76 on the arm 74 due to one end of the pawl riding over the cam portion *f* of the sector 70. The lever may now be moved from "charge" to "start" position or from the notch *b* to notch *c* in the sector 70. This movement causes the lever arm 95 to further open the valve 21 and also to engage the head 26 on the valve 22 and effect an opening of such valve. Thereupon the compressed air from chamber 16 flows through the pressure regulator 33 and non-return check valve 34 to the "charge" chamber 17, the valves 48 and 56 being now closed, and also flows through lines 30, 31 and 8 to build up pressure in the direct bounce reservoirs 10. This pressure also acts through line 88 on piston 86. Chamber 17 should charge to the full pressure permitted by the reducer valve before chambers 10 reach their charge pressures, and it is the function of valve 37 to produce the necessary restriction in line 31. When the pressure in chambers 10 reaches a certain predetermined value, piston 86 overcomes the effect of spring 83 and snaps the toggle 79, 81 back to its initial raised position, and consequently moves the rocker arm 74 quickly to its forward initial position. This simultaneously opens valve 48 and closes valve 51, causing the high pressure air to be delivered from the chamber 17 through line 47 to piston 43 and opening vent valves 41 in reverse bounce chambers 5b, and at the same time shutting off the high pressure supply to chamber

pressure of the spring 83, the plunger 86 will be moved outward to cause an outward movement of the center pin 85 past dead center position, causing the spring 83 to then act to quickly return the rocker arm 74 to its right end position, as shown in Fig. 2 of the drawings.

The rocker arm 74 has a rod 90 pivoted thereto and projecting forwardly therefrom, or to the right, and through a guide bracket 91 rising from the body 15. The free end of this rod bears against the upwardly and forwardly extending arm of a bell-crank lever 92 that is fulcrumed on the body 15, while the other arm of such lever extends rearwardly and upwardly and bears upwardly against the head 50 on the stem of the valve 48 and in opposition to the spring 49. When the rocker arm 74 is in its right end position, the rod 90 acts on the lever 92 to hold the valve 48 raised in its open position and during the initial rearward movement of the arm 74 the opening pressure of the lever 92 on the valve is released, thus permitting a closing of such valve.

A bell-crank lever 93 is fulcrumed to the bracket 91 and has a horizontally extending arm adapted to engage the stem head 53 of the valve 51, so as to move such valve from closed position when the lever arm is moved upward. The other arm of said lever extends downwardly and has an aperture therein through which the rod 90 extends. During a movement to the left of the rocker arm 74 and when it is near the limit of such movement, a shoulder 94 on the rod 90 engages the downwardly projecting arm of the lever 93 and moves the lever to effect an unseating of the valve 51, thus admitting air from a high pressure air supply in 127 to the pressure chamber 16. This unseating action of the valve 51 is rapid due to the rapid movement of the rocker arm 74 under the action of the spring 83.

The control lever 72 has an arm 95 projecting to the right from its inner end and provided with apertures through which the stems of the valves 21 and 22 project. During the movement of the control lever 72 from its "off" to "charge" position, arm 95 will engage first the head 26 of the valve 21 and cause an opening of such valve to permit the pressure in the chamber 16 to pass through the line 27 and valves 28, 29 therein to the reverse bounce connection 9, and thence to the two reverse bounce chambers 5^b to impart outward stroke movements to the piston sets. The control lever 72 is retained in the "charge" position until the pistons 6 have reached their extreme outer position, the piston heads closing off ports 11 and continuing until they are in contact with or just miss the ends of the cylinders 7.

The control lever 72 is then moved from notch *b* to *c* on the sector 70. During this movement, the arm 95 will act on the head 26 of the valve 22 and force said valve open against the compression of its spring 25, thus permitting compressed air to pass from the storage chamber 16 into the line 30 and through branch 32 to chamber 17 and through branch 31 to the direct bounce chamber connection 8 so as to build up a pressure in such connection and in the chambers 10 sufficient to force the engine pistons to their inward positions at the required velocity.

When the pressure in chambers 10 has built up to a predetermined value, this acts through line 98 against the plunger 86 to move the operating connection 79, 81 of the rocker arm upwardly past dead center position so as to permit the spring 83 to act to quickly throw said arm to its right hand position at which time valve 51 is permitted to close and valve 48 is caused to open. The valve 48 is held open so that the pressure in the chamber 17 is admitted through the lines 47 and 45 to the cylinder 42 to act against the pistons 43 therein to open the valves 41 and relieve any pressure in the reverse bounce chamber 5^b, which might oppose inward movement of the pistons.

A rod 100 extends from the control lever 72 near the inner end to a lever 101 to which it pivotally connects, such lever being fulcrumed to a bracket 102 rising from the body extension 65, and the lower end of such lever is provided with a cam foot 103 acting against the outer end of the stem 64 of the valve 62. This arrangement is such that when the lever 72 is in its "off" position, the valve 62 is closed, and when the control lever is moved away from such position, the cam 103 acts against the valve stem to open the valve, thus permitting the pressure in the line 61 to act against the plunger 58. It will be understood that after starting and during a running of the engine, the pressure in the line 61 fluctuates with the pressure in the direct bounce chambers so that if the connection of this line with the cylinder 59 were not cut off during such running of the engine, the valve 56 would have a fluttering action. It is for this reason that the starting mechanism is equipped with means for opening the line 61 to the chamber 59 during a starting operation and to close such connection when starting has been effected.

Before outward movement of the engine pistons 1, effected by admission of air pressure to the reverse bounce chambers 5^b of the engine, the direct bounce chambers 7 are vented, in the present instance, by means operated automatically by the starter mechanism in conjunction with pressure control governors for the engine. Such governors are shown and claimed in Patent No. 2,435,970, by Frank M. Lewis, one of the applicants herein. These governors are illustrated in Fig. 1 and designated "A" and "B," the former controlling the direct bounce chamber pressure and the latter the reverse bounce chamber pressure. The operation of these governors need only be described sufficiently in the present case to make their operation in connection with the starting mechanism clear.

Governor A includes four pressure responsive means 105, 106, 107 and 108, together with a spring 109 acting on a lever 110 to hold it in a closed position when the engine is operating properly. These bellows have connection, respectively, through lines 111, 112, 113 and 114 with the compressor chambers 5^a, the reverse bounce chambers 5^b, the direct bounce chambers 7 and the scavenging receiver 115. The line 113 connects with the direct bounce chamber line 8 through a pressure controlled mechanism operated by the lever 110, whereby a lowering of the right end of such lever will cause the direct bounce pressure to be increased by the admission of air pressure thereto, and a raising of such end of the lever will cause a venting of the bounce chamber pressure.

This venting of the bounce chamber pressure is accomplished automatically as follows: When the engine is stopped the reverse bounce pressure is vented through governor B as hereinafter described, thus relieving pressure in the pressure responsive means 106 of governor A, which causes an unbalancing of the pressures against lever 110 and permits the spring 109 to force the right end of the lever upward. This raises valve 116 and permits pressure from fuel oil supply line 117 to

16. The air in the direct bounce reservoirs 10 must leak around the circumferential clearance of the bounce piston 6 at its extreme outward position, before it can get behind the piston and do work. While this relatively slow process is taking place, the air in the reverse bounce chambers 5b will have dropped approximately to atmospheric pressure due to opening the valve 41. The pistons then move to their inner stroke positions, compressing the fuel charge for combustion. During this stroke the vent valves 41 are still held open, since the escape of air from behind the valves is prevented by valve 56. When the direct bounce pressure has dropped to some predetermined pressure, spring 60 overcomes the gas load on the piston 58 allowing valve 56 to open and then the air holding the vent valves open bleeds to the atmosphere. The drop in pressure behind the vent valves will be governed by the opening of needle valve 57 and the volume of the chamber 17. These quantities will be so regulated that the valve springs 44 in connection with the valves will not overcome the air pressure and close the vent valve 41 until some time during the outward power strokes of the engine pistons, after the proper air quantity has been taken into the reverse bounce chambers 5b to effect an energy balance for the stroke. Starting having been effected in this manner, control lever 72 may then be returned at leisure to its "off" position and its latch engaged with the sector notch a. The movement of the lever 92 of the starter mechanism to permit closing of the valve 48, which movement occurs during the rearward or left hand stroke of the starter control member 75, moves the rod 148 attached to such lever, causing a rocking of the lever 146 and an opening of the valve 144 in the high pressure air line 143, thus permitting such pressure to act through the line 142 on the pistons 139 and move the block-off valves 138 to close the line 113 of governor A and line 125 of governor B, thus preventing the venting of both the direct bounce and reverse bounce chambers. This movement of the rod 148 also moves the vent valve 149 to closed position to prevent any venting of the lines 142, 143. The return of the control member 75 to its normal position permits closing of the valve 144 and moves the vent valve 149 to position to vent the passage 150, thus relieving the pressure holding the block-off valves 138 closed and permitting them to open under the pressures of their springs. The governors A and B are thus again rendered operative in connection with the operation of the engine.

We wish it understood that our invention is not limited to any specific construction, arrangement or form of the parts, as it is capable of numerous modifications and changes without departing from the spirit of the claims.

Having thus described our invention, what we claim as new, and desire to secure by United States Letters Patent, is:

1. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, means operable to connect said source first with the reverse bounce chamber and then with the direct bounce chamber to move said piston first on its working stroke and then on a compression stroke, said means operating to vent said reverse bounce chamber prior to movement of said piston on a compression stroke and automatic means for cutting off the source connection to both said chambers when a predetermined pressure has been obtained in the direct bounce chamber.

2. An arrangement as called for in claim 1, together with means operable to vent said direct bounce and reverse bounce chambers when the engine is at rest, and means operable by the first mentioned means to render said vent means inoperable during predetermined portions of a starting operation.

3. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, manually operable means to connect said source first with the reverse bounce chamber and then with the direct bounce chamber, an exhaust valve for the reverse bounce chamber, and automatic means responsive to a predetermined direct bounce chamber pressure for opening said exhaust valve after the direct bounce chamber is connected to said source.

4. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, manually operable means to connect said source first with the reverse bounce chamber and then with the direct bounce chamber, an exhaust valve for the reverse bounce chamber, and automatic means responsive to predetermined pressure in the direct bounce chamber for opening said exhaust valve and for cutting off the connections to said source.

5. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, two valves for connecting said source with said chambers respectively, and manually operable means movable in one direction to first open the valve to the reverse bounce chamber and further on its movement to open the valve to the direct bounce chamber, an exhaust valve for the reverse bounce chamber, and means operable by pressure connected to the direct bounce chamber to open said exhaust valve.

6. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising an auxiliary chamber connected by a leakage passage to the direct bounce chamber when the engine piston is at the end of its working stroke and by open ports when the piston has moved a short distance on its compression stroke, a source of gas under pressure, a manually operable valve for connecting said source with said reverse bounce chamber, a manually operable valve for

connecting said source with said auxiliary chamber, an exhaust valve for the reverse bounce chamber, and means operable by pressure in said auxiliary chamber to open said exhaust valve.

7. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, means providing a storage chamber for gas under pressure, manually operable means for connecting said source to said storage chamber and connecting said storage chamber to said reverse bounce chamber, manually operable means to thereafter connect said storage chamber to said direct bounce chamber, means to vent said reverse bounce chamber after a predetermined pressure has been attained in said direct bounce chamber and automatic means responsive to direct bounce chamber pressure to break the connection between said source and said storage chamber.

8. An arrangement as called for in claim 7, together with vent means operable to vent both said bounce and reverse bounce chambers when the engine is stopped, and means for rendering said vent means inoperable during predetermined portions of a starting operation.

9. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, means providing a storage chamber for gas under pressure, manually operable means for connecting said source to said storage chamber and connecting said storage chamber to said reverse bounce chamber, manually operable means to thereafter connect said storage chamber to said direct bounce chamber, an exhaust valve for the reverse bounce chamber, and automatic means operable by pressure connected to said direct bounce chamber to break the connection from said source to said storage chamber and to open said exhaust valve.

10. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, manually operable means to connect said source first with the reverse bounce chamber and then with the direct bounce chamber, an exhaust valve for the reverse bounce chamber, automatic means responsive to direct bounce chamber pressure for opening said exhaust valve after the direct bounce chamber is connected to said source, and automatic means to close said exhaust valve after the piston starts on its next working stroke.

11. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, means operable to vent said bounce chamber when the engine is stopped, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, manually operable means to connect said source first with the reverse bounce chamber and then with the direct bounce chamber, an exhaust valve for the reverse bounce chamber, automatic means responsive to direct bounce chamber pressure for opening said exhaust valve after the direct bounce chamber is connected to said source, and automatic means to close said exhaust valve after the piston starts on its next working stroke, and means operable by said manually operable means to render said vent means inoperable during admission of the gas pressure to said reverse bounce and direct bounce chambers during a starting operation.

12. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, manually operable means to connect said source first with the reverse bounce chamber and then with the direct bounce chamber, an exhaust valve for the reverse bounce chamber, automatic means responsive to direct bounce chamber pressure for opening said valve, automatic means to close said exhaust valve after the completion of the compression stroke, and means for adjusting the last said means so that a predetermined portion of the next working stroke elapses before the exhaust valve closes.

13. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, manually operable means to connect said source first with the reverse bounce chamber and then with the direct bounce chamber, an exhaust valve for the reverse bounce chamber, and automatic means for opening said exhaust valve after the direct bounce chamber is connected to said source, said automatic means comprising a toggle, connections to said manually operable means for breaking the toggle in one direction, a spring for holding the toggle broken, a piston connected to said toggle, a cylinder around said piston, and means providing a passage from the direct bounce chamber to said cylinder to straighten the toggle when a predetermined pressure is present in the direct bounce chamber.

14. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, a storage chamber, manually operable means for connecting said source to said storage chamber and connecting said storage chamber to said reverse bounce chamber, manually operable means to thereafter connect said storage chamber to said direct bounce chamber, an exhaust valve for the reverse bounce chamber, and automatic means operable by pressure connected to said direct bounce chamber to break the connection from said source to said storage chamber and to open said exhaust valve, said automatic means comprising a toggle,

connections to said manually operable means for breaking the toggle in one direction, a spring for holding the toggle broken, a piston connected to the toggle, a cylinder around said piston, and means providing a passage from the direct bounce chamber to said cylinder to straighten the toggle when a predetermined pressure is present in the bounce chamber.

15. A starter for an internal combustion engine of the free piston type having a direct bounce chamber, compression in which tends to move the engine piston in the direction of its compression stroke, and a reverse bounce chamber, compression in which tends to move the piston in the direction of its outward stroke, comprising a source of gas under pressure, manually operable means to connect said source first with the reverse bounce chamber and then with the direct bounce chamber, an exhaust valve for the reverse bounce chamber, and automatic means for opening said exhaust valve after the direct bounce chamber is connected to said source, said automatic means comprising a spring normally closing said exhaust valve, a piston and cylinder pressure which overcomes the spring and opens the valve, means for introducing and trapping valve-opening pressure in said cylinder, and a leak passage allowing gas to escape from said cylinder.

16. An arrangement as called for in claim 15, together with means normally standing open and responsive to pressure in said direct bounce chamber to close said leak passage, and means normally rendering said responsive means inoperative and manually operable to render said responsive means operable.

17. An apparatus for controlling starting of an internal combustion free piston machine having an air compressor piston subject on one side to air in an air compressing chamber and on the opposite side to air in a reverse bounce chamber, a rigidly connected power piston operable by products of combustion from compression ignition in a power chamber to actuate said compressor piston on an air compression stroke, and direct bounce air cushion means for actuating said piston on an air intake stroke and to provide compression ignition, said apparatus comprising reverse bounce supply means for supplying fluid under pressure to said reverse bounce chamber for moving said pistons on an air compression stroke to a starting position, direct bounce supply means operable upon movement of said pistons to said starting position to supply fluid under pressure to said air cushion means, vent valve means for releasing fluid under pressure from said reverse bounce chamber to render said fluid under pressure in said cushion means effective to move said pistons on said intake stroke to provide compression ignition, and sequence means operable upon a chosen increase in pressure in said cushion means to effect operation of said reverse bounce supply means to cut off supply of fluid under pressure to said reverse bounce chamber and to also effect operation of said vent valve means to release fluid under pressure from said reverse bounce chamber.

18. An apparatus for controlling starting of an internal combustion free piston machine having an air compressor piston subject on one side to air in an air compressing chamber and on the opposite side to air in a reverse bounce chamber, a rigidly connected power piston operable by products of combustion from compression ignition in a power chamber to actuate said compressor piston on an air compression stroke, and direct bounce air cushion means for actuating said piston an an air intake stroke and to provide compression ignition, said apparatus comprising reverse bounce supply means for supplying fluid under pressure to said reverse bounce chamber for moving said pistons on an air compression stroke to a starting position, direct bounce supply means operable upon movement of said pistons to said starting position to supply fluid under pressure to said air cushion means, vent valve means for releasing fluid under pressure from said reverse bounce chamber to render said fluid under pressure in said cushion means effective to move said pistons on said intake stroke to provide compression ignition, sequence means operable upon a chosen increase in pressure in said cushion means to effect operation of said direct bounce supply means and reverse bounce supply means to cut off the supply of fluid under pressure to, respectively, said cushion means and said reverse bounce chamber and to also effect operation of said vent valve means.

19. An apparatus for controlling starting of an internal combustion free piston machine having an air compressor piston subject on one side to air in an air compressing chamber and on the opposite side to air in a reverse bounce chamber, a rigidly connected power piston operable by products of combustion from compression ignition in a power chamber to actuate said compressor piston on an air compression stroke, and direct bounce air cushion means for actuating said piston on an air intake stroke and to provide compression ignition, said apparatus comprising reverse bounce supply means for supplying fluid under pressure to said reverse bounce chamber for moving said pistons on an air compression stroke to a starting position, direct bounce supply means operable upon movement of said pistons to said starting position to supply fluid under pressure to said air cushion means, vent valve means for releasing fluid under pressure from said reverse bounce chamber to render said fluid under pressure in said cushion means effective to move said pistons on said intake stroke to provide compression ignition, sequence means operable upon a chosen increase in pressure in said cushion means to effect operation of said direct bounce supply means and reverse bounce supply means to cut off the supply of fluid under pressure to, respectively, said cushion means and said reverse bounce chamber and to also effect operation of said vent valve means, and means operable upon a chosen reduction in pressure of fluid in said cushion means to effect operation of said vent valve means to terminate release of fluid under pressure from said reverse bounce chamber.

20. An apparatus for controlling starting of an internal combustion free piston machine having an air compressing piston subject on opposite sides to pressure of air in air compressing and reverse bounce chambers, respectively, a rigidly connected power piston for moving said compressing piston in the direction against air in said air compressing chamber, and direct bounce fluid pressure cushion means for moving said piston in the opposite direction, said apparatus comprising first valve means for supplying fluid under pressure to said reverse bounce chamber for moving said pistons to a chosen position in the first named direction, second valve means for supplying fluid under pressure to said cushion means, vent valve means for venting the fluid under pressure from said reverse bounce cham-

ber, and means for effecting operation of said vent valve means upon a chosen increase in pressure in said cushion means.

21. An apparatus for controlling starting of an internal combustion free piston machine having an air compressing piston subject on opposite sides to pressure of air in air compressing and reverse bounce chambers respectively, a rigidly connected power piston for moving said compressing piston in the direction against air in said air compressing chamber, and direct bounce fluid pressure cushion means for moving said piston in the opposite direction, said apparatus comprising valve means for supplying fluid under pressure to said reverse bounce chamber and to said cushion means, means for delaying supply of fluid under pressure to said cushion means with respect to supply of fluid under pressure to said reverse bounce chamber, means for cutting off said supply of fluid under pressure to and for bottling up the fluid pressure in said cushion means, vent valve means for venting the fluid under pressure from said reverse bounce chamber, and means responsive to a certain increase in pressure in said cushion means to effect operation of said vent valve means.

22. An apparatus for controlling starting of an internal combustion free piston machine having an air compressing piston subject on opposite sides to pressure of air in air compressing and reverse bounce chambers, respectively, a rigidly connected power piston for moving said compressing piston in the direction against air in said air compressing chamber, and direct bounce fluid pressure cushion means for moving said piston in the opposite direction, said apparatus comprising means for supplying fluid under pressure to said reverse bounce chamber to move said pistons to a chosen position in the first named direction, means for limiting to a chosen degree the pressure of fluid supplied to said reverse bounce chamber, means for supplying fluid under pressure to said cushion means, means for limiting to a chosen higher degree the pressure of fluid supplied to said cushion means, vent valve means for venting fluid under pressure from said reverse bounce chamber, and means responsive to a chosen increase in pressure in said cushion means to effect operation of said vent valve means.

23. An apparatus for controlling starting of an internal combustion free piston machine having an air compressing piston subject on opposite sides to pressure of air in air compressing and reverse bounce chambers respectively, a rigidly connected power piston for moving said compressing piston in the direction against air in said air compressing chamber, and direct bounce fluid pressure cushion means for moving said piston in the opposite direction, said apparatus comprising a first valve means for supplying fluid under pressure to said reverse bounce chamber for moving said pistons to a chosen position in the first named direction, fluid pressure operable vent valve means for releasing fluid under pressure from said reverse bounce chamber, a feed valve device operable upon supply of fluid under pressure to a first communication to supply fluid at a reduced pressure from said communication to said cushion means and to another communication, choke and check valve means in the fluid supply communication to said cushion means, a check valve for preventing reverse flow of fluid under pressure from said other communication, a second valve means for supplying fluid under pressure to said first communication, a third valve means for opening said other communication to said vent valve means, and means for effecting sequential operation of said first, second and third valve means in the order named.

24. An apparatus for controlling starting of an internal combustion free piston machine having an air compressing piston subject on opposite sides to pressure of air in air compressing and reverse bounce chambers respectivey, a rigidly connected power piston for moving said compressing piston in the direction against air in said air compressing chamber, and direct bounce fluid pressure cushion means for moving said piston in the opposite direction, said apparatus comprising a first valve means for supplying fluid under pressure to said reverse bounce chamber for moving said pistons to a chosen position in the first named direction, a second valve means for supplying fluid under pressure to said cushion means, means for delaying operation of said second valve means with respect to operation of said first valve means, vent valve means for opening a vent from said reverse bounce chamber for releasing fluid under pressure therefrom to render said pistons movable by pressure of fluid in said cushion means, means responsive to a chosen increase in pressure in said cushion means to effect operation of said vent valve means to open said vent, and means operable in response to a reduction in pressure in said cushion means to effect operation of said vent valve means to close said vent.

25. An apparatus for controlling starting of an internal combustion free piston machine having an air compressing piston subject on opposite sides to pressure of air in air compressing and reverse bounce chambers, respectively, a rigidly connected power piston for moving said compressing piston in the direction against air in said air compressing chamber, and direct bounce fluid pressure cushion means for moving said piston in the opposite direction, said apparatus comprising first valve means for supplying fluid under pressure to said reverse bounce chamber, second valve means for supplying fluid under pressure to said cushion means, vent valve means operable by fluid under pressure to open a fluid pressure vent from said reverse bounce chamber for releasing fluid therefrom to render said pistons movable by pressure of fluid in said cushion means, exhaust valve means for releasing fluid under pressure from said vent valve means to effect operation thereof to close said vent, and means for delaying operation of said second valve means with respect to operation of said first valve means and for effecting first supply of fluid under pressure to said vent valve means and then operation of exhaust valve means, subsequent to operation of said second valve means.

FRANK M. LEWIS.
WILLARD A. MORAIN.

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