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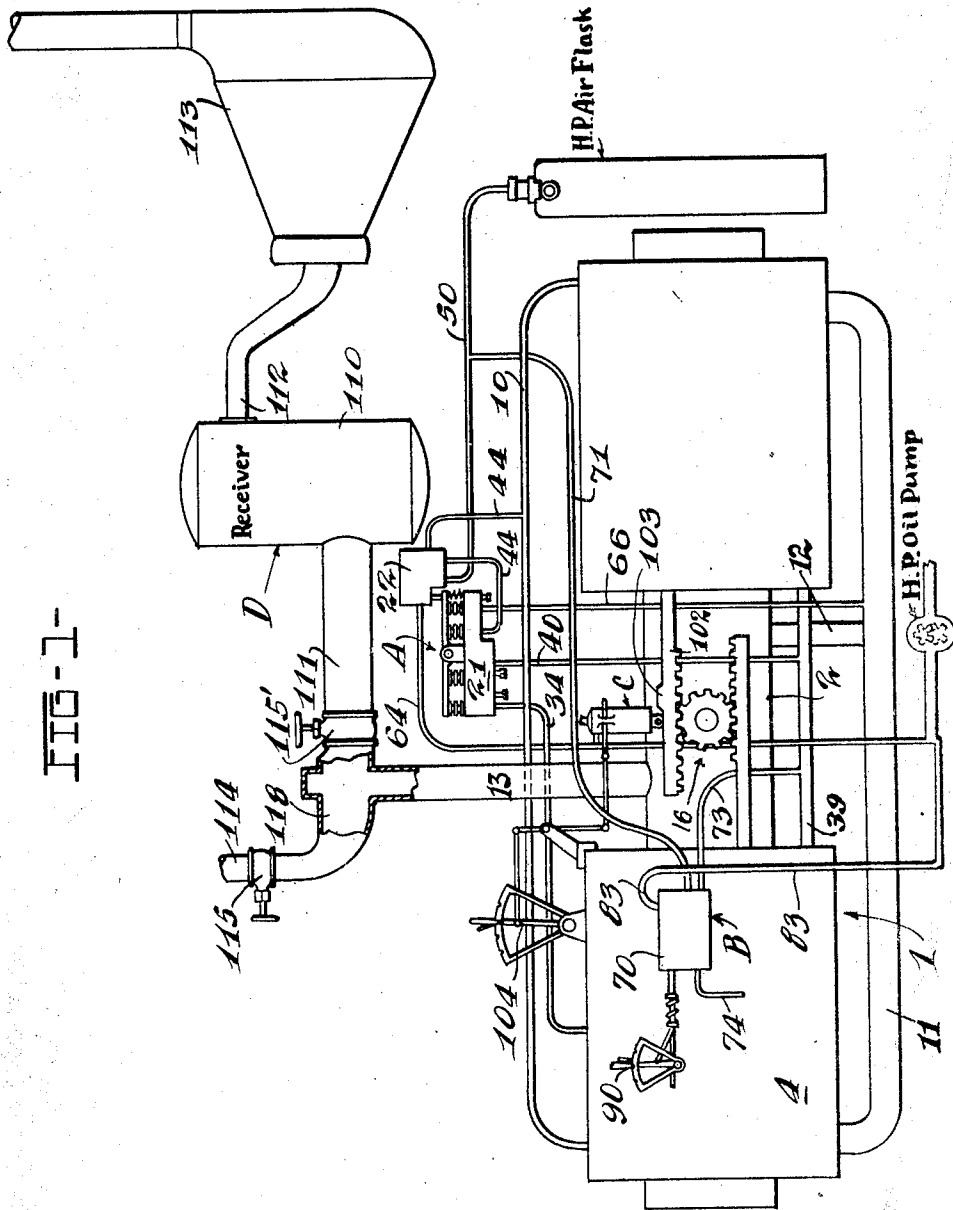
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2,435,970

FREE PISTON ENGINE PRESSURE CONTROL MEANS

Filed June 14, 1945

3 Sheets-Sheet 1



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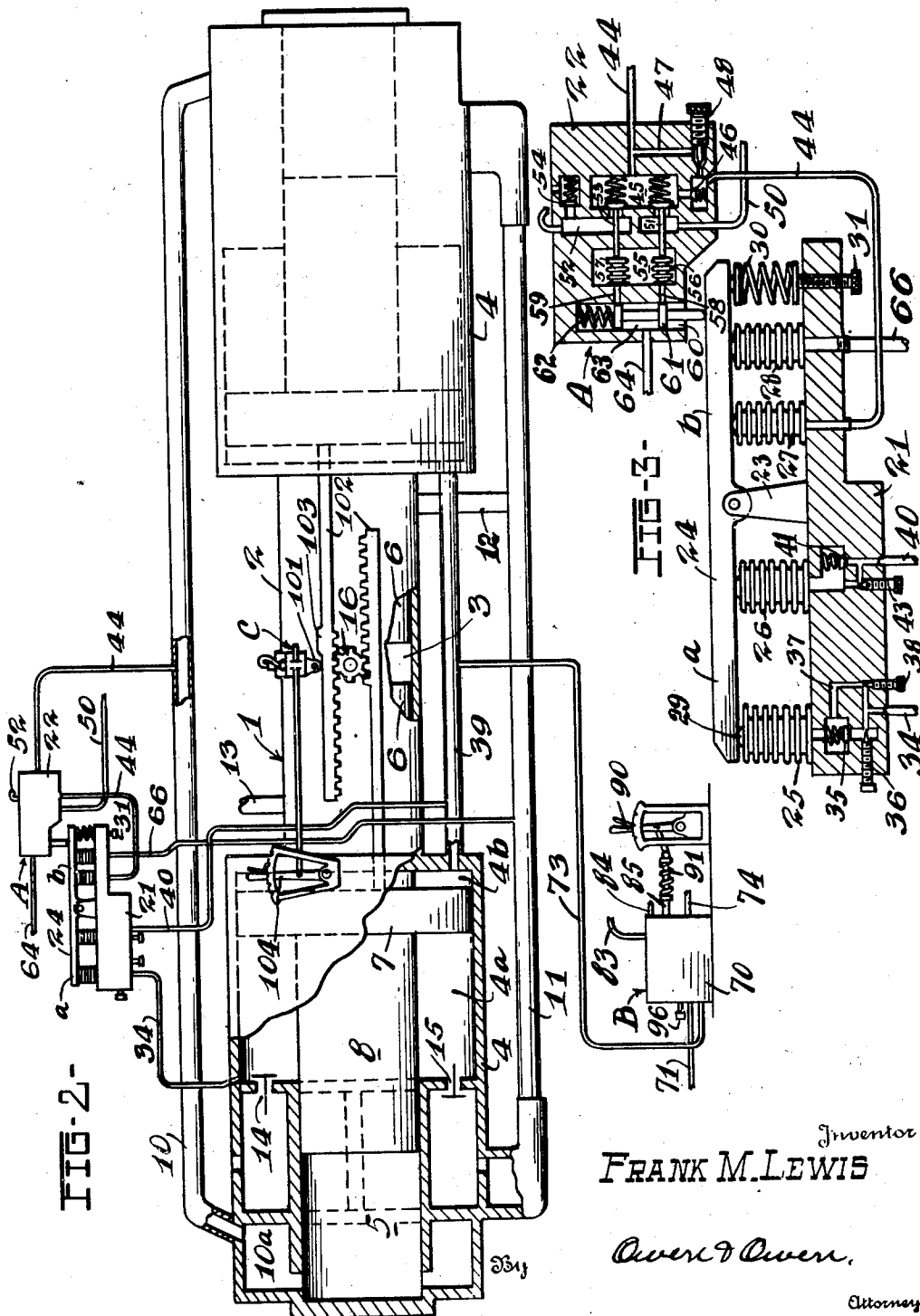
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FREE PISTON ENGINE PRESSURE CONTROL MEANS

Filed June 14, 1945

3 Sheets-Sheet 2



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FREE PISTON ENGINE PRESSURE CONTROL MEANS

Filed June 14, 1945

3 Sheets-Sheet 3

FIG-4-

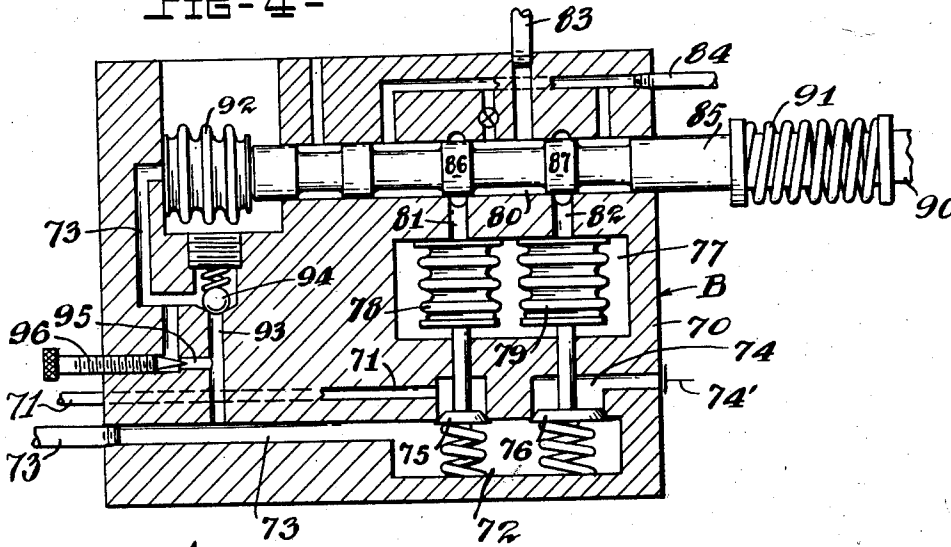
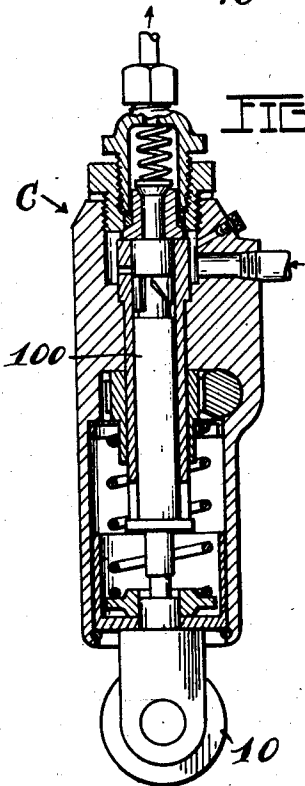


FIG-5-



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UNITED STATES PATENT OFFICE

2,435,970

FREE PISTON ENGINE PRESSURE
CONTROL MEANS

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Application June 14, 1945, Serial No. 599,361

41 Claims. (Cl. 123-46)

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This invention relates to pressure balancing means for use in connection with engines of the free piston type and to a method of control.

The present application is a continuation in part of my application Serial No. 548,115, filed August 4, 1944, now abandoned.

The apparatus and method relate particularly to the employment of an internal combustion engine of the free piston type to supply hot gas under pressure for driving a turbine or for other purposes. The engine power is utilized to pump air into a scavenging receiver from which it passes to scavenge the combustion chamber, from which chamber it is discharged, together with the products of combustion, into a turbine or other means for utilizing the discharged gases.

In such engines, it has been found highly desirable, for proper operation, to cause the free pistons to generate, not only a direct bounce pressure, a compressor pressure and a scavenging receiver pressure, as has heretofore been accomplished, but also a reverse bounce pressure, and to regulate said pressures to maintain proper relationship therebetween. Since the movement of the pistons is dependent upon the relationship of the pressures tending to move them in opposite directions, it is necessary, for proper operation, to maintain a proper relationship between the said several pressures, and to increase or decrease the direct bounce pressure in accordance with a variance of some or all of the other pressures.

It will be seen that any variance in the pressure against which the exhaust is discharged changes the pressure in the scavenging receiver and that in turn changes the length of the stroke, the mean pressure in the compressor, the direct bounce pressure and the reverse bounce pressure. Similarly, any change in the fuel consumption on each stroke varies the stroke and each of the pressures involved to at least some extent. Also, incidentally, variations in the operation of the motor, due to increased or decreased friction, variations in gas transfer from any cause, changes in temperature, etc., result in changed pressures.

Obviously, the output of the engine may be varied by varying the fuel supply. However, there is a tendency for the stroke to vary with the amount of fuel consumed on each stroke, and since the exhaust and inlet ports are in fixed positions, the stroke must have a certain length in order for these ports to function properly. This sets a lower limit to the variation in fuel without other adjustments. Similarly, the length of the cylinders sets obvious upper limits to control by amount of fuel alone.

One object of this invention is to provide a means and method for controlling an engine of this type whereby relatively wide variation may be obtained at will in the output while contin-

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uing to operate within close limits as to exhaust gas pressures.

Another object is to provide for idling the engine with a minimum of fuel on each stroke and a minimum of stroke frequency when output is not to be utilized.

Another object is to control the cyclic frequency at or near the normal maximum output without variation in the fuel on each stroke or excessive stroke variation, by controlling the maximum direct and reverse bounce pressures.

Another object is to enable the machine to produce gas for limited periods of time in excess of that being delivered at the normal maximum output.

Another object is to provide a manually operable governor whereby the peak reverse bounce pressure is automatically maintained substantially constant for successive cycles at the selected amount of pressure determined by the governor setting.

Another object is to provide an automatic governor which maintains the proper relation of pressures, including the maximum direct and reverse bounce pressures, the weighted mean compressor pressure, and the scavenging receiver pressure, through all operations of the engine, from idling to maximum output.

Another object of the invention is to provide a governor which automatically increases or decreases the maximum direct bounce pressure to restore the proper relation of pressures upon any change in the maximum direct bounce pressure, the weighted mean compressor pressure, or the scavenging receiver pressure.

Further objects and advantages of the invention will be apparent from the following detailed description, and from the accompanying drawings, in which—

Fig. 1 is a diagrammatical view of a gas generator of the internal combustion free piston engine type equipped with the various control means embodying the present invention and with parts broken away; Fig. 2 is an enlarged diagrammatical view of the engine with the direct bounce and the reverse bounce pressure governors associated therewith and with parts of the engine broken away and removed; Fig. 3 is an enlarged sectional detail of the direct bounce pressure governor; Fig. 4 is an enlarged sectional detail of the reverse bounce pressure governor, and Fig. 5 is an enlarged sectional detail of the fuel feed pump.

Referring to the drawings, 1 designates a more or less diagrammatical showing of a free piston engine, which comprises a casing 2 forming at its center a combustion chamber 3, at each of its opposite ends an air compressor cylinder 4, and at the outer end of each of such cylinders a direct bounce chamber 5. Opposed power pistons 6, 6 operate in the combustion chamber 3

and each of these attaches to an air compressor piston 7 in the respective cylinder 4. Each piston 7 divides its cylinder into a compression chamber 4a and a reverse bounce pressure chamber 4b and has a piston 8 projecting from its outer side into the respective direct bounce chamber 5.

The direct bounce chambers 5 are in communication through an equalizing pipe 10 and an auxiliary chamber 10a at each end, the function of which latter is covered by my co-pending application Serial No. 549,909, now Patent 2,434,277, January 13, 1948. A scavenging receiver 11 has a port connection 12 with one end portion of the combustion chamber 3, so that its cylinder end is uncovered by the closing piston 6 at the end of its power or expansion stroke. An exhaust passage 13 is provided near the other end of the combustion chamber in position to be uncovered by its closing piston 6 near the end of its power or expansion stroke, but before the opening of the scavenging port connection, as is well understood in the art. The compressor chambers 4a have valve controlled air admission ports 14 and exhaust ports 15. The opposite sets of pistons are connected by a synchronizing means 16 to cause them to operate in unison.

The control features comprise a governor A by which the maximum direct bounce pressure is automatically maintained so that there is a proper balance between that and the scavenging receiver pressure, the maximum reverse bounce pressure and the weighted mean compressor pressure; a governor B by which the maximum reverse bounce pressure is maintained constant at the chosen amount for which the governor is set; a fuel pump C through which the fuel feed is controlled, and means for controlling the pressure in exhaust gas receiver D. These controls will be taken up and described in the order given above.

The direct bounce governor A (Fig. 3) includes a stationary body which may be divided into two fixedly associated parts 21 and 22, the latter, in the present instance, being disposed above and in partial overhanging relation to the former.

The body part 21 is in the form of a support or platform, and has a standard or bracket arm 23 projecting therefrom, in the present instance upwardly, and carrying at its outer end a pressure equalizing lever 24 for rocking movements in a plane preferably normal to the adjacent surface of the support. This lever has oppositely projecting arms a and b.

Four power translating elements 25, 26, 27 and 28, in the present instance in the form of Sylphon bellows, are interposed between the support 21 and lever 24 in spaced relation lengthwise thereof, with the first two acting against the arm a and the last two acting against the arm b of the lever. These bellows expand away from the support 21 toward the lever and each has a point or pivotal bearing 29 against the lever. The spacing and the effective relative sizes of the bellows and their cooperating functions depend, of course, on the desired results and the pressures applied, and will vary with different designs of associated engine. A pressure compensating spring 30 is also interposed between the support 21 and lever 24, and acts, in the present instance, against the outer end portion of the lever arm b. This spring has at one end a point or pivotal end thrust against the lever and has its other end engaged by an adjusting screw 31 that is mounted in the support.

In the present instance, the air pressure in at

least one of the compressor chambers 4a is in communication with the stationary end of the bellows 25 through a passage line 34 which extends through the support 21 and includes a check valve 35, opening toward the bellows, and a needle valve 36. The line 34 also has a return leak passage 37 around the valves 35 and 36 with a needle valve 38 therein.

The reverse bounce spaces 4b of the engine are in communication through a connection 39 and this connection is in communication with the interior of the bellows 26 through a line 40 which extends through the support 21 and has a check valve 41 therein opening toward the bellows. This line also has a return leak passage around the check valve and controlled by a needle valve 43. The pressure in the spaces 4b and connection 39 are controlled by the governor B, as hereinafter described.

The pressure in the bellows 27 is maintained at substantially that of the maximum pressure in the direct bounce chambers 5 of the engine through a connecting line 44 with the direct bounce connection 10. The line 44 is through the body part 22 of the governor in which a pressure equalizing means for said line, operating in conjunction with unbalanced movements of the lever 24, is located. In the present instance, the line 44 is through a pressure equalizing chamber 45 in the part 22, and a check valve 46 is located in the line between said chamber and the bellows 27 and opens toward the bellows. A return leak passage 47, having a needle valve 48 therein, is provided in the connection 44 around the check valve 46. The chamber 45 has communication with a suitable source of high pressure air supply through a passage 50 that is controlled by an inwardly opening check valve 51. Said chamber also has an exhaust passage 52 leading therefrom that is normally closed by an inwardly opening check valve 53 and an outwardly opening check valve 54. Each of these valves is held normally seated by a spring of predetermined pressure.

The valves 51 and 53 have their stems projecting into a chamber or pocket 55 in the part 22 and attached therein to the free or movable end of respective bellows 56 and 57, which connect at their opposite ends through respective ports 58 and 59 with a valve chamber 60. A plunger type of valve 61 is mounted for reciprocatory movements in this chamber and is normally held in outwardly projected position by a spring 62 in the inner end of the chamber with its outer end in thrust engagement with the outer end portion of the lever arm b in opposition to the thrust against such arm of each of the bellows 27, 28, and the spring 30. The valve has a central cut-away portion which cooperates with the chamber 60 to form a pressure space 63 that has communication through a passage 64 with a suitable fluid pressure supply source, with the fluid preferably oil.

It will be seen that the connections of direct bounce chambers to bellows 27 and the reverse bounce chambers to bellows 26, by means of check valves and bleed valves, is such that approximately the maximum pressures in these bounce chambers are reached in the bellows on each stroke, the effective passage being so much greater for admitting gas to the bellows than for allowing its escape. The pressure in the scavenging pressure receiver is so nearly constant, when that receiver is of large size, that only direct connection between the receiver and

bellows 28 is shown; but if the receiver in a particular installation should be small enough to result in troublesome fluctuations in pressure in the bellows with such direct connection, a suitably restricted opening could be provided to dampen the fluctuations.

In the normal operation of the compressor the pressure therein varies from a low during filling of the chamber 4a to a high when discharge starts, the pressure during discharge remaining constant. The connection from the compressor chamber to bellows 25 is provided with needle valve 36, so that the pressure in the bellows is dependent upon the length of time during which discharging pressure continues, and is a weighted mean pressure of the compressor chamber instead of being substantially the maximum pressure of the associated chambers, as in the case of bellows 26 and 27. By adjustment of needle valves 36 and 38 the proper weighting of the mean pressure is effected.

When the valve, in the operation of the governor A, is in what may be termed a position of equilibrium, in which position the lever 24 is also in equilibrium, both ports 58 and 59 are closed, and if the valve is moved outwardly from such position upon an inward movement of the engaged end of the lever, the port 58 is uncovered to the pressure space 63, and if the valve is moved inwardly from such position by an outward movement of the engaged end of the lever, the port 59 is uncovered to said space. An opening of the port 58 admits to the bellows 56 a pressure which is greater than the closing forces acting against the valve 51, thus effecting an opening of such valve to admit high pressure air to the chamber 45 to raise the pressure in the part of line 44 leading to the bellows 27 whereby the bellows is caused to exert a predetermined increased outward moving force against the lever. The additional air so admitted also raises the working pressure level of the direct bounce chambers 5 as communication exists between chamber 5 and chamber 45 via the lines 44 and 10. An uncovering of the port 59 likewise admits to the bellows 57 a pressure which is greater than the force tending to maintain the valve 53 closed, so as to open such valve and permit an exhaust of pressure from the chamber 45 and consequently to reduce the pressure in the section of the line 44 to the bellows 27 and in said bellows sufficient to overcome the unbalancing force acting against the arm b of the lever and permit the lever to return to a position of equilibrium. As the pressures existing in bellows 27 are substantially the maximum pressures attained in the direct bounce chambers 5, a reduction of the quantity of air in chambers 5 by the opening of valve 53 allows the pressure in bellows 27 to bleed out through the needle valve 48 to a value where lever 24 is again in equilibrium. This new value of the pressure in bellows 27 is also in equilibrium with the new value of the maximum pressures obtained in chamber 5.

The bellows 28 is in communication with the scavenging receiver 11 through a connection 66, so that the movement of such bellows is responsive to a change of pressure in the receiver 11.

It is evident from the foregoing that under proper operating conditions of the engine the air compressor weighted mean pressure and the reverse bounce maximum pressure acting against the lever 24 at one side of its fulcrum through the bellows 25 and 26, respectively, are opposed by the adjusted pressure of the spring 30, together

with the direct bounce maximum pressure and the actual scavenging receiver pressure acting through the bellows 27 and 28, respectively, against the other end portion of the lever, and that these various pressures are such that the lever will be held in a position of substantial equilibrium during normal engine operating conditions. It is also evident that the governor action, whereby the lever is held in equilibrium against a variation of engine generated pressures tending to move it from such position, is effected by an automatic increasing or decreasing of the pressure in one of the actuating bellows, 27 in the present instance, which change of pressure results from an unbalanced movement of the lever due to the responsive movement of the lever actuated control valve 61.

The direct bounce maximum pressure, the air compressor weighted mean pressure, the reverse bounce maximum pressure and the scavenging receiver pressure of a properly operating engine being known, it is a comparatively simple matter to calculate the pressures necessary to act on the lever through the several bellows and the spring 30 to maintain the lever in a position of equilibrium.

It will be readily understood that the direct bounce pressure should be increased when the reverse bounce pressure is increased, to properly relate the forces on the pistons, also that when resistance to the working stroke is lowered by lowering of the scavenging pressure the direct bounce pressure should be increased. The compressor pressure acts on the same side of the piston as the direct bounce pressure, and so it might be thought it should be on the same side as the direct bounce and scavenging pressures. However, an increase in the direct bounce pressure tends to stop the working stroke short of the place it would reach with less direct bounce pressure. Other things remaining equal, this shortened stroke leaves more compressed gas in the compressor at the end of the stroke, and so adds to the energy utilized in returning the piston to firing position. The utilization of the weighted mean compressor pressure to aid the rebound pressure in balancing the direct bounce and scavenging pressures thus operates to control the strokes properly.

It will be seen, however, that the general structure of governor A makes it possible to automatically adjust the pressure in one chamber to compensate for other changed pressures, whether the compensation should be in the same or in the opposite direction from said change.

The reverse bounce governor B, in its present embodiment (Fig. 4), includes a body 70 having a high pressure air supply line 71 in valve controlled communication with a chamber 72 which in turn has connection through a line 73 with the reverse bounce space equalizer pipe 39. A pressure release or exhaust passage 74 also extends from the chamber 72. Normally closed valves 75 and 76, respectively, control the communication between the chamber 72 and the supply line 71 and exhaust passage 74 which latter has a check valve 74' therein.

The stems of the valves 75 and 76 project into a space 77 in the body 70 and connect therein with fluid pressure responsive means in the nature, in the present instance, of Siphon bellows 78 and 79, respectively, whereby expansive movements of said bellows will open the valve. These bellows receive their pressure supply from a valve chamber 80 through respective ports 81, 82, and the valve chamber in turn receives its supply from

a suitable source, preferably of high pressure oil, through a line 83. A leak-off passage 84 has communication with the chamber 80 at the outer side of each passage 81, 82.

A plunger type of valve 85 is mounted for longitudinal reciprocatory movements in the chamber 80 and is recessed on opposite sides of lands 86 and 87, which are adapted to simultaneously close the ports 81, 82, when the valve is in one position, or to alternately open each of such ports to the supply passage 83 or to the leak-off 84, upon movement of the valve in one direction or the other from port closing position, as is apparent. Thus, a movement of the valve to the left from neutral position will open the port 81 to the supply line 83 and open port 82 to the leak-off 84, while its movement to the right from such position will open the port 82 to the supply line and the port 81 to the leak-off.

The valve 85 is yieldingly moved to the left by a manual control 90 operating on its right end through a compression spring 91, and is moved to the right against said spring pressure by a fluid pressure responsive means 92. In the present instance, this means comprises a Sylphon bellows which has its movable end bearing against the left end of the valve and receives its fluid pressure from the line 73 through a connection 93 having a check valve 94 therein opening toward the bellows. This connection also has a bleed passage 95 around the valve 94 controlled by a needle valve 96. With this arrangement, the valve 85 will be moved to the left when the pressure of the spring 91 predominates over the reverse bounce pressure in the line 73, and will be moved to the right by the responsive pressure means 92 when the reverse bounce pressure predominates over that of the spring. When the first-mentioned condition is present, high pressure oil will be admitted to the bellows 78 and cause it to expand and open the check valve 76 to admit high pressure air from the line 71 to the chamber 72 and line 73. When the pressure in line 73 has thus been increased sufficiently to predominate over the spring 91 and to expand the bellows 92, the control valve 85 will be moved to the right against the tension of the spring 91 to close the port 81. When the second-mentioned condition is present, high pressure oil will be admitted to the bellows 79 and cause it to expand to open the check valve 76 to relieve the pressure in the chamber 72 and reverse bounce pressure line 73 through the exhaust passage 74. Accordingly, the pressure in the reverse bounce pressure line 73 will be increased or diminished as the tension of spring 91 is increased or diminished.

The fuel pump C for injecting fuel charges into the combustion chamber 3 of the engine, when the power pistons 6 are substantially at the ends of their compression strokes, is, in the present instance, of the plunger type shown in Fig. 5, with the outer end of its plunger 100 provided with a roll 101 traveling on one of the rack-bars 102 of the piston synchronizing means 16. A fuel charge injection is effected at the proper time by a cam projection 103 on the rack-bar passing under the plunger roll. The quantity of feed is controlled by a rotary adjustment of the plunger, and this is accomplished manually by a rack-bar and pinion connection therewith of a lever control 104. Both a manual and automatic means for accomplishing such adjustment are disclosed and claimed in a co-pending application, Serial No. 558,360, filed October 12, 1944.

The exhaust gas receiver D commonly used with gas generators for receiving and supplying the exhaust gas therefrom to a turbine includes a receiver 110, which receives the exhaust gas from the engine through a pipe connection 111 and discharges such gas through an outlet line 112 to the turbine 113. The exhaust line 111 has a relief outlet line 114 to the atmosphere controlled by a valve 115. There is also a valve 116 located in the line 111 between the exhaust conduit 13 and the receiver. It is thus apparent that the exhaust from the line 13 may be directed either through the line 111 into the receiver or through the line 114 to the atmosphere by an adjustment of the valves 115 and 116.

In the general operation of the present gas generator unit the pistons are caused to reciprocate by means of the pressure exerted on the various faces of the piston. The pistons are forced outward on their power strokes by the expansive energy of the fuel burning in the power cylinder 3 and by the residual energy contained in the reverse bounce spaces 4b. The pistons in moving outward are resisted by the pressures in the air compressor spaces 4a and in the direct bounce cylinders 5. The direct bounce pressure rises in proportion to the length of the piston travel, while the air compressor pressure increases to a predetermined value and levels off at that value. The machine is so designed that at a certain point in the outward stroke of the pistons these pressures attain a sufficient magnitude to overcome the forces of the power cylinder, the momentum of the piston, and the residual energy of the reverse bounce spaces and thereby cause a reversal in the direction of the piston movement after the power cylinder has exhausted. The balance of energy is again reached when the power pistons reach the inner dead center position after compressing a charge of air prior to combustion and also compressing, to a predetermined value, the air contained in the reverse bounce spaces and their connecting pipes.

The purpose of the governor A is to maintain the proper relation of the direct bounce pressure to the scavenging receiver pressure, the reverse bounce pressure and the compressor pressure. It will be understood that the relationship of the pressures may be disturbed by increase or decrease of the reverse bounce pressure, by variance in the fuel supply, by variance in the pressure in the exhaust receiving chamber, or by any other variance, accidental or intentional, which results in a variance in the length or position of the reciprocation of the pistons or otherwise varies any one of the pressures. In regaining its equilibrium, lever 24 automatically reestablishes the pressure relation of the various bellows and their respective engine chambers. A movement of the lever 24 to an unbalanced position is responsive to a variation of pressure in any one of the bellows, so that the right hand end of the lever is lowered or raised in accordance with the pressure variations. This movement of the lever either causes or permits a movement of the governor control valve 51 whereby, upon a lowering of the adjacent end of the lever, the plunger is moved to admit an operating pressure to the bellows 56 which in turn causes an opening of the valve 51 and an admission of high pressure air to the direct bounce line 44 to increase the pressure therein an extent sufficient to move the lever back to neutral or equilibrium, which in turn moves the valve 51 to close the bellows port 56. If the pressure in the

bellows is such as to raise the end b of the lever 24 and throw it out of balance, the control plunger 61 is raised, thus admitting pressure to the bellows 57 to effect an opening of the relief valve 53, which permits a retarded reduction in pressure in the bellows 27, by properly regulated leakage through the passage 47 past the check valve 46, and a consequent balancing of the pressure against the lever 24 to permit it to return to neutral.

It will be seen from the foregoing that the governor A takes care of maintaining the proper relationship among the various pressures concerned to maintain the proper functioning of the engine. It will be understood that the positions and sizes of the several bellows must be calculated for the particular engine and the desired working conditions, and that the needle valves are adjusted so that the response to variations will be properly timed and fluctuations, due to variations in pressure during a piston cycle, will be sufficiently dampened. Needle valves 36 and 38 are adjusted so that the mean compressor pressure is properly weighted to maintain proper relationship of pressures to produce the desired functioning of the piston for the particular apparatus involved.

Since governor A operates upon any disturbance of the relationship of pressures due to any cause whatever, it functions in cooperation with the other controls, the operation of which will now be described.

Presuming that the fuel control is set to supply the maximum fuel to be utilized on each stroke, the operation of the engine will be at or near its full load output per stroke. Under these conditions, the output per stroke of the machine will remain substantially constant. The total output therefore varies substantially directly with the cyclic frequency. The speed of the pistons, and thus the frequency and the total output, is increased by an increase of pressures in the rebound chambers, and vice versa. The pressure in the rebound chamber may be set at, or changed to, the desired amount by governor B, as will be now described.

The operation of governor B is such that on a compression of the spring 91 by a movement of the control lever 90 the valve 85 is caused to shift to the left against the yielding resistance of the bellows 92. This movement causes the valve 75 to open as high pressure fluid is admitted into bellows 78, and the opening of such valve admits high pressure air from the line 71 into the line 73 connecting with the reverse bounce spaces 4b. However, an increase of pressure in these spaces tends to expand the bellows 92, thus relocating the valve 85 again in a neutral position. The energy balance of the entire machine would now be distorted except for the action of the governor A, the function of which, as previously described, is to maintain for any given maximum pressure value existing in the reverse bounce chambers, also for any predetermined weighted mean pressure in the air compressor cylinders and for any pressure in the scavenging receiver, a proper direct bounce maximum pressure. Thus, as the pressure in the reverse bounce chambers is intentionally varied by movement of the control valve lever 90, a proper balance relation is restored between the various pressure chambers by governor A, thereby causing the engine to operate properly, though under different pressure and cyclic conditions.

When it is desired to reduce the engine output and the cyclic frequency below that which may be obtained by normal minimum reverse bounce

pressures, it becomes necessary to control the engine by means of the quantity of fuel injected.

Reduction of the fuel supplied at each stroke disturbs the relationship of pressures, but governor A automatically restores the proper relationship, as described above. However, as the fuel is reduced, the stroke is shortened, and particularly the outward movement of the pistons on their working stroke is shortened, until a point is reached where the energy of the fuel charge will no longer drive sufficient gas out of the compressor against the standard pressure in the scavenging receiver to allow the pistons to uncover the exhaust and scavenging ports sufficiently for proper functioning.

In order to have the engine function properly under idling conditions, the pressure against which the compressor works must be lowered to enable the pistons to reach exhausting and scavenging positions. This may be done by closing valve 115' and opening partially or fully valve 115, which reduces the pressure against which the exhaust is discharged. This in turn reduces the pressure in the scavenging receiver and also the pressure against which the compressor discharges, while maintaining the exhausting and scavenging functions of the engine. In this way, the pressures are reduced until the engine is exhausting only at or slightly above atmospheric pressure and the compressor is operating only sufficiently to scavenge the engine against such pressure.

At this stage the engine is idling, with the scavenging receiver pressure, weighted mean compressor pressure and direct bounce and rebound pressures at substantially a minimum, but still maintained in proper relationship by governor A, with a supply of fuel sufficient only to keep the engine operating under these conditions and with the frequency as low, and each stroke as long, as the nature of the particular engine will allow. Thus, idling is maintained with less fuel than would be possible without a governor to adjust the pressure for that condition.

In any case, every increase in fuel and every change in the open or closed relationship of valves 115 and 115' upsets the relationship of the pressures, and their proper relation is restored by governor A.

After the relief valve 115 is fully closed and 115' opened, increased output of gas may be obtained merely by increasing fuel until the normal maximum gas output is reached. During this increase of fuel, the proper relation of the pressures is taken care of by governor A. Without this governor, each change in amount of fuel would vary the relation of pressures from the optimum. By use of the governor A, the engine can be operated throughout the entire output range at a much nearer approach to maximum efficiency than would be possible without the governor. Thus, an efficient operation of the engine is maintained from a very low idling speed to a point where the full charge of fuel for most efficient operation is delivered at each stroke.

To further increase the output, governor B is operated to increase the pressure in the reverse bounce chamber, and governor A increases the direct bounce pressure in compensation until maximum pressures of direct bounce and rebound, maximum frequency, and maximum output are reached.

The several controls cooperate to make possible an efficient operation of the engine from a lower

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idling frequency than would be feasible without the controls up to a higher total output than would be feasible without the controls. The governor A could be used alone under any conditions where any of the pressures involved is subject to variation rendering compensation desirable. The governor B can be used for adjusting and maintaining the desired rebound pressure however the other pressures are controlled. Therefore, these governors are separately usable, although they cooperate in the entire system of control to accomplish a total result impossible when any one of the control features is omitted.

It will be readily recognized that many changes may be made in the specific construction and arrangement of parts within the scope of the appended claims, and that for any given installation the construction and adjustment will be modified to suit the requirements of that installation.

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

1. In an internal combustion engine of the free piston type having a normally closed bounce chamber, means for connecting said chamber temporarily to a source of gas under pressure higher than that in said chamber, and means to connect said chamber temporarily to a source of gas under a pressure less than that in said chamber, whereby the pressure in said chamber may be increased or decreased.

2. In an internal combustion engine of the free piston type having a normally closed bounce chamber, a source of gas under pressure higher than that in said chamber, an exhaust passage leading to gas pressure less than that in said chamber, and valves normally closed but movable to connect said chamber to said source and to said exhaust passage alternately.

3. In an internal combustion engine of the free piston type having a normally closed bounce chamber and means responsive to a running of the engine for developing other pressures which should be maintained in proper relation to the pressure in the bounce chamber, a source of gas under higher pressure than that in the bounce chamber, an exhaust passage to a lower pressure than that in the bounce chamber, normally closed valves movable to alternatively connect said chamber to said supply or to said exhaust passage, and means actuated by said other pressures for moving said valves to maintain said proper relation.

4. The combination with a free piston engine wherein during an operation thereof direct bounce, scavenging receiver, air compressor and reverse bounce pressures are present, of a governor for maintaining a properly balanced condition of said pressures, which governor includes a movable member responsive to a predetermined relationship of said pressures to substantially hold it in a position of equilibrium, and means in operative connection with said member and having connection with at least one of said pressures and responsive to different predetermined movements of the member to vary said last pressure relative to the other pressures an extent necessary to maintain the member in a position of equilibrium.

5. An arrangement as called for in claim 4 together with a yielding manually adjustable pressure means coacting with the movable member in cooperation with said engine pressures to main-

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tain a substantially balanced condition of said member during a running of the engine.

6. The combination with a free piston engine wherein during an operation thereof direct bounce and other predetermined fluid pressures are present, of a governor for maintaining a substantially predetermined balanced condition of said pressures upon a change of engine frequency, which governor includes a movable member, means responsive to a predetermined relationship of said pressures to substantially hold said member in a position of balance under a predetermined engine frequency and operable to move the member from such position upon a change of engine frequency, and means in operative connection with said member and having connection with said direct bounce pressure and responsive to a movement of said member from a balanced position upon a change of engine frequency to compensate for the resulting bounce pressure change and return the member to balance.

7. The combination with a free piston engine wherein during an operation thereof direct bounce and other predetermined fluid pressures are present, of a governor for maintaining a substantially predetermined balanced condition of said pressures upon a change of engine frequency which governor includes a movable lever, means responsive to said pressures and acting on said lever to hold it in substantially a position of predetermined balance under a predetermined engine frequency and operable to move the lever from such position upon a change of frequency, and means in operative connection with said lever and operable upon a change in engine frequency to vary the direct bounce pressure action on said lever an extent necessary to maintain said member in balanced position.

8. The combination with a free piston engine wherein during an operation thereof direct bounce, scavenging receiver, air compressor and reverse bounce pressures are present, of a governor for maintaining a substantially predetermined balanced condition of said pressures upon a change of engine frequency, which governor includes a lever, means responsive to said pressures and acting on said lever to move it from a position of substantial balance upon a change of predetermined engine frequency, and pressure control means in connection with the portion of said first means which is responsive to the direct bounce pressure and automatically operable upon a change of the engine frequency to increase or diminish such pressure to compensate for a variance therein and to maintain said lever in substantially its position of balance.

9. An arrangement as called for in claim 8 together with spring means acting on the lever in cooperation with said responsive means to assist in maintaining a balanced position of the lever.

10. The combination with a free piston engine wherein during an operation thereof direct bounce, scavenging receiver, air compressor and reverse bounce pressures are present, of a governor for maintaining a substantially predetermined balanced condition of said pressures upon a change of engine frequency, and including a movable balanced member, separate means connected to and responsive to said engine pressures and acting in predetermined relation on said member to substantially maintain it in a predetermined position of balance and to move it from such position upon a change of engine frequency, manually adjustable balance correc-

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tive pressure means for said member, and pressure control means in connection with one of said separate means and automatically operable upon a member unbalancing movement due to a change of engine frequency to increase or diminish the member moving pressure of said last-mentioned separate means to compensate for the pressure change occurring upon an engine frequency change.

11. The combination with a free piston engine wherein during an operation thereof direct bounce, scavenging receiver, air compressor and reverse bounce pressures are present, of a governor for maintaining a substantially predetermined balanced condition of said pressures upon an engine frequency change, said governor including a movable balance member, a plurality of pneumatically responsive elements each having connection with and being responsive to a particular one of said engine pressures and arranged to act on said member to hold it in a substantially balanced position during a running of the engine, and pressure control means in connection with at least one of said separate means and operable by and upon a change of engine frequency to vary the member balancing pressure to compensate for said change.

12. An arrangement as called for in claim 11 together with manually adjustable pressure means acting on the balance member to assist in balancing the pressures thereon of said pneumatically operated elements.

13. The combination with a free piston engine, wherein during an operation thereof direct bounce, scavenging receiver, air compressor and reverse bounce pressures are present, of a governor for maintaining a substantially balanced condition of said pressures upon an engine frequency change, said governor including a balance lever, a plurality of pneumatically operable means each having connection with a particular one of said engine pressures and acting in predetermined relation on said lever in response to said pressures to maintain it in a predetermined position of balance when the engine is running at a predetermined frequency, and to vary the lever position when the engine frequency changes, and means controlled by the lever movements to return said pressures to a predetermined balanced condition.

14. The combination with a free piston engine wherein during an operation thereof direct bounce, scavenging receiver, air compressor and reverse bounce pressures are present, of a governor for maintaining a substantially balanced condition of said pressures upon an engine frequency change, said governor including a balance lever, a plurality of pneumatically operable means each having connection with a particular one of said engine pressures and acting in predetermined relation on said lever in response to said pressures to maintain it in a predetermined position of balance when the engine is running at a predetermined frequency and to vary the lever position when the engine frequency changes, and means controlled by the lever movements to return said pressures to a predetermined balanced condition, said last means having an exhaust passage and a high pressure air passage and including means controlled by movements of the lever to open one or the other of said passages to the pressure acting on one of said first means to increase or diminish such pressure depending on the lever movement.

15. An arrangement as called for in claim 14 together with manually adjustable pressure

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means acting on said lever to assist in balancing the pressures thereon of said pneumatically operated means.

16. The combination with a free piston engine wherein during an operation thereof direct bounce and other predetermined fluid pressures are present, of a governor for maintaining a substantially balanced condition of said pressures upon an engine frequency change, said governor including a balance lever, a plurality of pneumatically operable members each having connection with a particular one of said engine pressures and acting in predetermined relation on said lever in response to said pressures to maintain it in a predetermined position of balance when the engine is running at a predetermined frequency and to vary the lever position when the engine frequency changes, and means controlled by lever movements to return said pressures to a predetermined balanced condition of said pressures, said last means having an exhaust passage and a high pressure air supply passage in normally closed valve controlled communication with the direct bounce pressure and including means controlled by movements of said lever to open one or the other of said passages to diminish or increase the bounce pressure to maintain a substantially predetermined balanced position of the lever.

17. An arrangement as called for in claim 16 together with manually adjustable pressure means acting on said lever to assist in balancing the pressures thereon of said members.

18. The combination with a free piston engine wherein during an operation thereof direct bounce, scavenging receiver, air compressor and reverse bounce pressures are present, of a governor for maintaining a substantially balanced condition of said pressures upon an engine frequency change, said governor including a balance lever, a plurality of pneumatically operable means each having a passage in communication with a predetermined one of said engine pressures and acting in predetermined relation on said lever in response to said pressures to maintain it in a predetermined position of balance when the engine is running at a predetermined frequency and to vary the lever position when the engine frequency changes, pressure control valves and check valves in the air compressor and reverse bounce pressure passages, and means controlled by lever movements to increase or diminish the rebound pressure applied to its responsive means to maintain a predetermined balanced condition of said pressures upon a change in engine frequency.

19. The combination with a free piston engine wherein during an operation thereof direct bounce, scavenging receiver, air compressor and reverse bounce pressures are present, of a governor for maintaining a substantially balanced condition of said pressures upon an engine frequency change, said governor including a balance lever, a plurality of pneumatically responsive means each having a passage in communication with a predetermined one of said engine pressures and acting in predetermined relation on said lever in response to said pressures to maintain it in a predetermined position of balance when the engine is running at a predetermined frequency and to vary the lever position when the engine frequency changes, pressure control valves and check valves in the air compressor and reverse bounce pressure passages, and means controlled by lever movements to increase or diminish the direct bounce pressure applied to its re-

sponsive means to maintain a predetermined balanced condition of said pressures upon a change in engine frequency, said last means having an exhaust passage and a high pressure air passage and including means controlled by movements of the lever to open one or the other of said passages to said direct bounce pressure passage to increase or diminish the pressure therein depending on the lever movement.

20. An arrangement as called for in claim 19 together with manually adjustable spring pressure means acting on said lever to assist in balancing the pressures thereon of said pneumatically responsive means for a predetermined engine frequency.

21. The combination with a free piston engine wherein during an operation thereof predetermined pneumatic engine pressures including a direct bounce pressure are present, of a governor for maintaining a substantially predetermined balanced condition of said pressures upon a change of engine frequency, which governor includes a movable member, means responsive to a predetermined relationship of said pressures to substantially hold said member in a position of balance under a predetermined engine frequency and operable to move the member from such position upon a change of engine frequency, and means in operative connection with said member and having connection with said direct bounce pressure and responsive to a movement of said member from a balanced position upon a change of engine frequency to compensate for the resulting bounce pressure change and return the member to balance.

22. An arrangement as called for in claim 21 together with manually adjustable spring pressure means acting on said member to assist in balancing the action thereon of said pressures.

23. In an internal combustion engine of the free piston type having a normally closed direct bounce chamber, a normally closed reverse bounce chamber, a manual control to vary the amount of gas in one of said chambers at will, and automatic means to correspondingly vary the amount of gas in the other chamber when it is varied in one chamber by manual control.

24. In an internal combustion engine of the free piston type having a normally closed direct bounce chamber and a normally closed rebound chamber, manually controlled means to vary the amount of gas in the reverse bounce chamber and automatic means to correspondingly vary the amount of gas in the direct bounce chamber.

25. In an internal combustion engine of the free piston type having a normally closed reverse bounce chamber, a source of supply of gas under pressure greater than that in said chamber, an exhaust passage to gas pressure lower than that in said chamber, normally closed valves movable to connect said chamber alternatively with said source and said passage, means exerting pressure from within the chamber to move said valves to exhausting position, and adjustable resilient means for moving said valves to supplying position.

26. The combination in a free piston engine, of means forming connected reverse bounce chambers, pistons operating to compress air in said chambers, and a means operable to increase or decrease the maximum air pressure in the reverse bounce chambers to change the engine frequency.

27. The combination in a free piston engine, of means forming direct and reverse bounce

chambers, pistons operating to alternately compress air in said chambers, a governor operable to increase or decrease the maximum air pressure in the reverse bounce chamber to change the engine frequency, and means for maintaining a predetermined balanced condition of said direct and reverse bounce pressures.

28. The combination in a free piston engine, of two sets of opposed pistons, cylinder means cooperating with said pistons to form direct and reverse bounce pressure chambers in which air is alternately compressed by reciprocatory movements of the pistons, means operable to increase or decrease the maximum pressure in the reverse bounce chambers a predetermined extent and to maintain the new pressures substantially constant, and means automatically operable to vary the direct bounce pressure in substantial accordance with the variance of the reverse bounce pressure to maintain said pressures in predetermined balance.

29. In a free piston engine, two opposed sets of free pistons, cylinder means cooperating with said pistons to form direct and reverse bounce pressure chambers in which air is alternately compressed, the frequency and length of strokes of the pistons being varied upon a variance in the maximum air pressures in said reverse bounce chambers, and control means in connection with the reverse bounce chambers and operable to vary the maximum reverse bounce pressure a predetermined extent and to maintain said variance substantially constant for a desired running period.

30. In a free piston engine, two opposed sets of free pistons, cylinder means cooperating with said pistons to form direct and reverse bounce pressure chambers in which air is alternately compressed, the frequency and length of strokes of the pistons being varied upon a variance in the maximum air pressures in said reverse bounce chambers, and control means in connection with the reverse bounce chambers and operable to vary the maximum reverse bounce pressure a predetermined extent and to maintain said variance substantially constant for a desired running period, said control means including a valve manually and yieldingly movable in one direction and pneumatically movable in the other direction, and means for admitting high pressure air to the reverse bounce chambers when the valve is moved in the first direction and to release pressure therefrom when the valve is moved in the opposite direction.

31. The combination with a free piston engine wherein during an operation thereof direct bounce, scavenging receiver, air compressor and reverse bounce pressures are created, of means operable to increase or decrease the maximum reverse bounce pressure in accordance with the frequency and length of piston stroke desired, a governor for maintaining a properly balanced condition of said pressures upon a change of engine frequency, which governor includes a movable member responsive to a predetermined relationship of said pressures to substantially hold it in a position of equilibrium, means in operative connection with said member and having connection with at least one of said pressures and responsive to different predetermined movements of the member to vary said last pressure an extent necessary to maintain the member in a position of equilibrium.

32. The combination with a free piston engine wherein during an operation thereof direct bounce and other predetermined fluid pressures are present, of means operable to increase or de-

crease a predetermined one of said other pressures to vary the engine frequency, a governor for maintaining a substantially predetermined balanced condition of said pressures upon a change of engine frequency, which governor includes a movable member, means responsive to a predetermined relationship of said pressures to substantially hold said member in a position of balance under a predetermined engine frequency and operable to move the member from such position upon a change of engine frequency, means in operative connection with said member and having connection with said direct bounce pressure and responsive to a movement of said member from balanced position upon a change of engine frequency to compensate for the resulting bounce pressure change and return the member to balance.

33. The combination with a free piston engine wherein during an operation thereof direct bounce, scavenging receiver, air compressor and reverse bounce pressures are present, of means operable to vary the maximum reverse bounce pressures to change the engine frequency, a governor for maintaining a substantially predetermined balanced condition of said pressures upon a change of engine frequency, which governor includes a lever, means responsive to said pressures and acting on said lever to move it from a position of substantial balance upon a change of predetermined engine frequency, and pressure control means in connection with the portion of said first means which is responsive to the direct bounce pressure and automatically operable upon a change of the engine frequency to increase or diminish such pressure to compensate for a variance therein and to maintain said lever in substantially its position of balance.

34. The combination with a free piston engine wherein during an operation thereof direct bounce, scavenger receiver, air compressor and reverse bounce pressures are present, of a manually controlled governor having connection with and operable to vary the reverse bounce maximum pressure a predetermined extent to change the engine frequency, a second governor for maintaining a substantially predetermined balanced condition of said pressures upon an engine frequency change, said governor including a movable balance member, a plurality of pneumatically responsive elements each having connection with and being responsive to a particular one of said engine pressures and arranged to act on said member to hold it in a substantially balanced position during a running of the engine, and pressure control means in connection with at least one of said separate means and operable by and upon a change of engine frequency to vary the member balancing pressure to compensate for said change.

35. The combination with a free piston engine wherein during an operation thereof predetermined pneumatic pressures including a direct bounce pressure and a reverse bounce pressure are present, of means operable to vary the reverse bounce maximum pressure a predetermined extent to change the engine frequency, a governor for maintaining a substantially predetermined balanced condition of said pressures upon a change of the reverse bounce maximum pressure, which governor includes a movable member, means responsive to a predetermined relationship of said pressures to substantially hold said member in a position of balance under a predetermined engine frequency and operable

to move the member from such position upon a change of engine frequency, and means in operative connection with said member and having connection with said direct bounce pressure and responsive to a movement of said member from a balanced position upon a change of engine frequency to compensate for the resulting bounce pressure change and return the member to balance.

36. The combination in a gas generator of the internal combustion free piston engine type, wherein during an operation thereof direct bounce, reverse bounce, air compressor and scavenger receiver pressures are present, and a predetermined balance of said pressures is necessary for proper running of the engine under different load and speed conditions, of manually controlled means for varying said reverse bounce pressure, manually controlled fuel injection means, certain of said pressures varying upon a change in engine speed due to a change in quantity of fuel injection per cycle, and means automatically operable both by a change in the reverse bounce pressure and by changes in others of said pressures upon a change in the engine speed to effect a predetermined balance of the direct bounce pressure with any changes in said pressures whereby a proper running condition of the engine is maintained.

37. The combination in a gas generator of the internal combustion free piston engine type wherein during an operation thereof direct bounce, reverse bounce, air compressor and scavenger receiver pressures are present, and a predetermined balance of said pressures is necessary for proper running under different load and speed conditions, of manually controlled means for increasing or reducing said reverse bounce pressure to obtain changed engine operating conditions, fuel injection means operable to effect a changed engine running condition whereby certain of said pressures are varied, and governor means having connection with said several pressures and automatically operable to maintain a predetermined balanced relation therebetween.

38. The combination in a gas generator of the internal combustion free piston engine type wherein during an operation thereof direct bounce, reverse bounce, air compressor and scavenger receiver pressures are present, and a predetermined balance of said pressures is necessary for proper running under different load and speed conditions, of manually controlled means for increasing or reducing said reverse bounce pressure to obtain changed engine operating conditions, a receiver for exhaust gases from the engine, means operable to vary said receiver pressure in relation to atmospheric pressure and thereby effect a change in predetermined running conditions of the engine which vary certain of said first-mentioned pressures, and governor means having connection with said several pressures and automatically operable to maintain a predetermined balanced relation therebetween.

39. The combination in a gas generator of the internal combustion free piston engine type wherein during an operation thereof direct bounce, reverse bounce, air compressor and scavenger receiver pressures are present, and a predetermined balance of said pressures is necessary for proper running under different load and speed conditions, of manually controlled means for increasing or reducing said reverse bounce pressure to obtain a changed engine running condition, fuel injection means operable to effect a

changed engine running condition whereby certain of said pressures are varied, a receiver for exhaust gases from the engine, means operable to vary said receiver pressure in relation to atmospheric pressure and thereby effect a change in predetermined running conditions of the engine which vary certain of said first-mentioned pressures, and governor means having connection with said several first-mentioned pressures and automatically operable to maintain a predetermined balanced relation therebetween.

40. The combination in a gas generator of the internal combustion free piston engine type wherein during an operation thereof direct bounce, reverse bounce, air compressor and scavenger receiver pressures are present, and a predetermined balance of said pressures is necessary for proper engine running under different load and speed conditions, of manually controlled means for increasing or reducing said reverse bounce pressure to obtain changed engine operating conditions, a fuel injection pump for the engine, a receiver for the engine exhaust gases, separate manually controlled means for changing the quantity of fuel feed effected by the pump and also the gas pressure in the receiver relative to the atmosphere, and a governor means having connection with each of said first-mentioned pressures and automatically operable to increase or diminish the direct bounce pressure in accordance with a variance of the reverse bounce

pressure and to maintain a predetermined balance between the direct bounce pressure and said air compressor and scavenger receiver pressures.

41. In apparatus comprising an internal combustion engine of the free piston type comprising a compressor, connections from the compressor for scavenging the engine, a chamber normally containing gas above atmospheric pressure, an exhaust connection to said chamber and a reverse bounce chamber, means for varying the fuel charge at each stroke from an idling minimum to the maximum utilizable, means to reduce the exhaust pressure to atmospheric during idling and thereby reduce the minimum output of the engine, and means to vary the pressure in the reverse bounce chamber to vary the engine frequency while the fuel charge remains at maximum.

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