Aug. 26, 1952 A. J. BENT 2,608,052

FLUID PRESSURE CONTROL APPARATUS FOR FREE PISTON MACHINES

Filed July 22, 1947 5 Sheets-Sheet 1

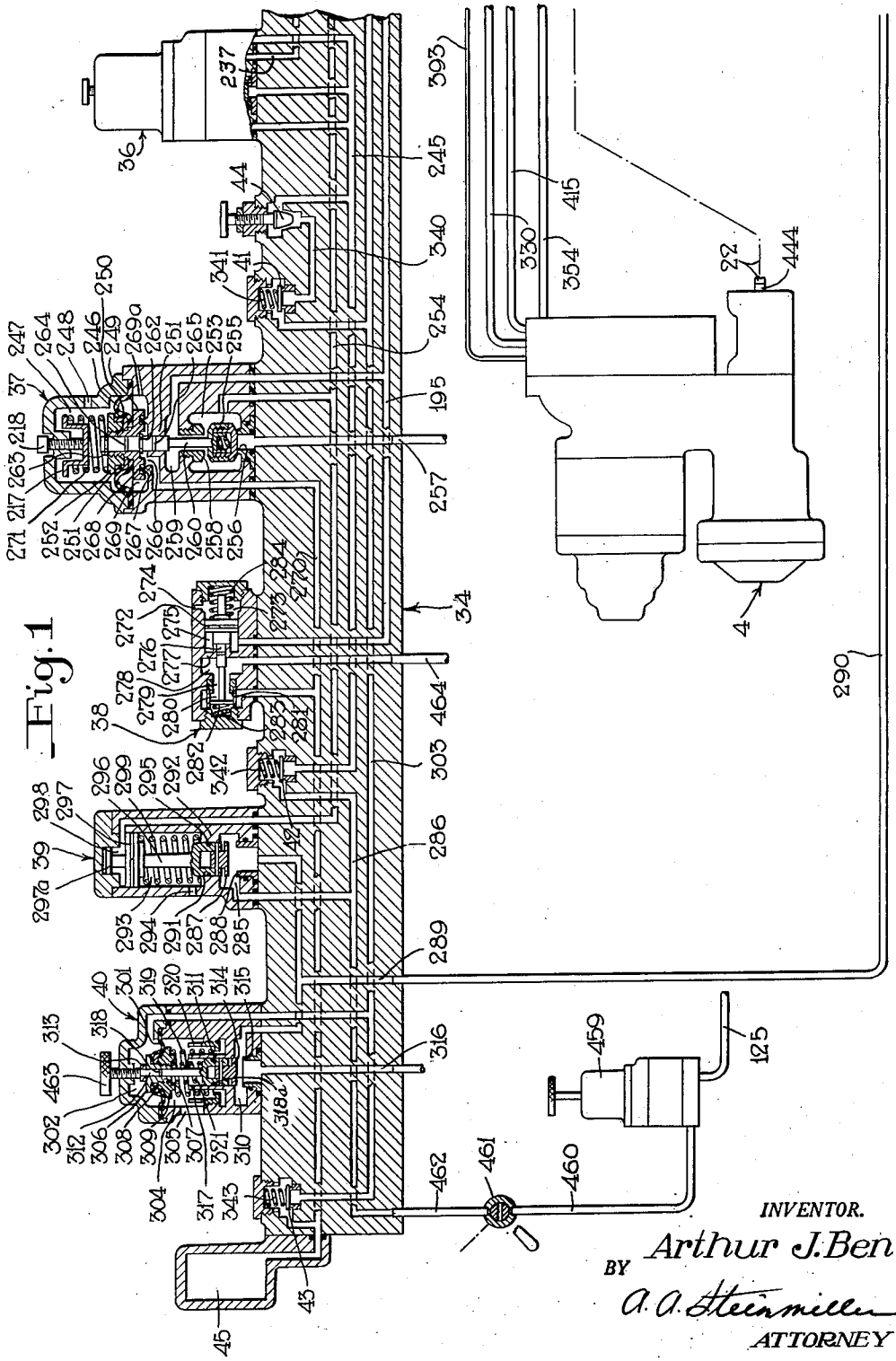


Fig. 1

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Fig. 1-A

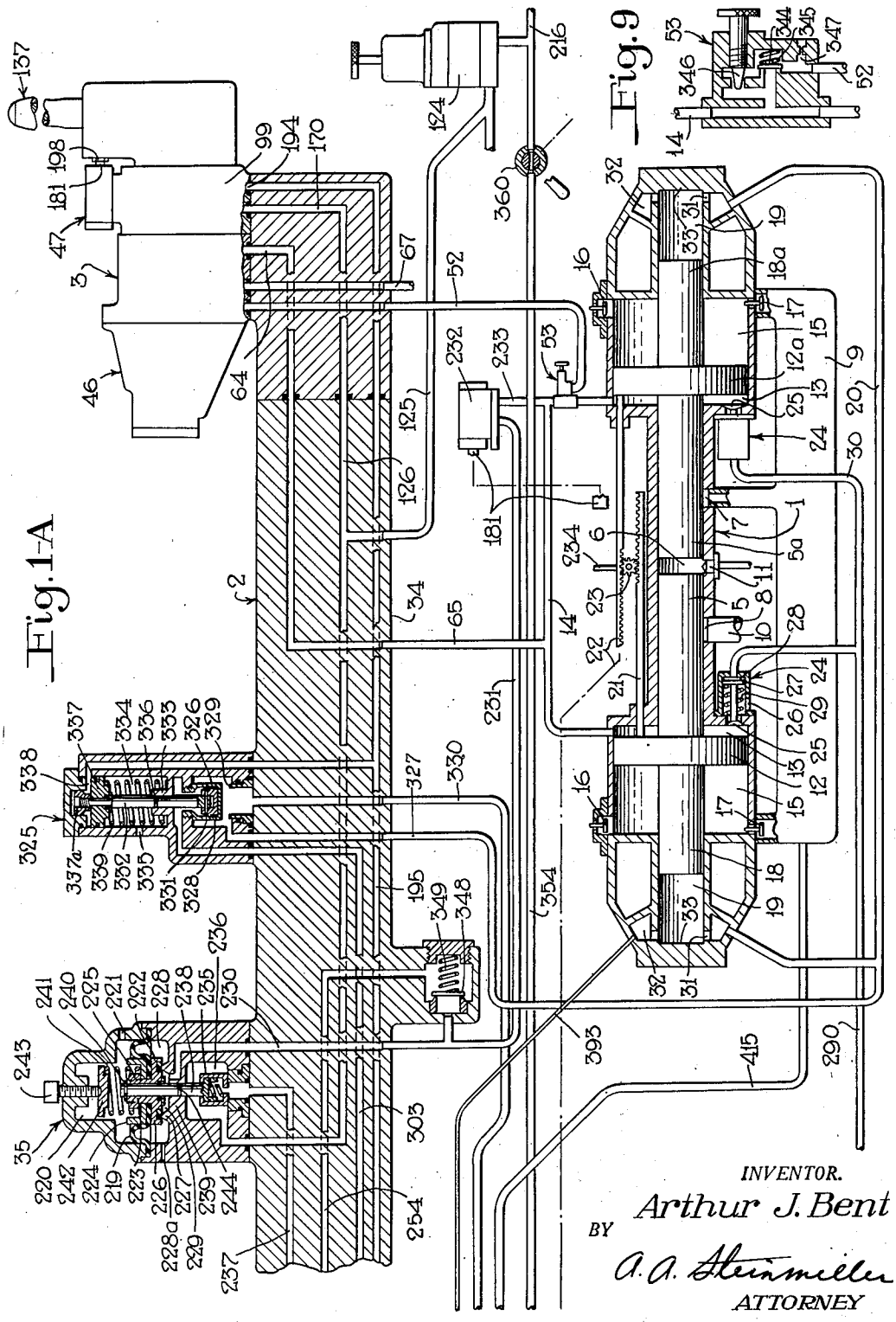


Fig. 9

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FLUID PRESSURE CONTROL APPARATUS FOR FREE PISTON MACHINES

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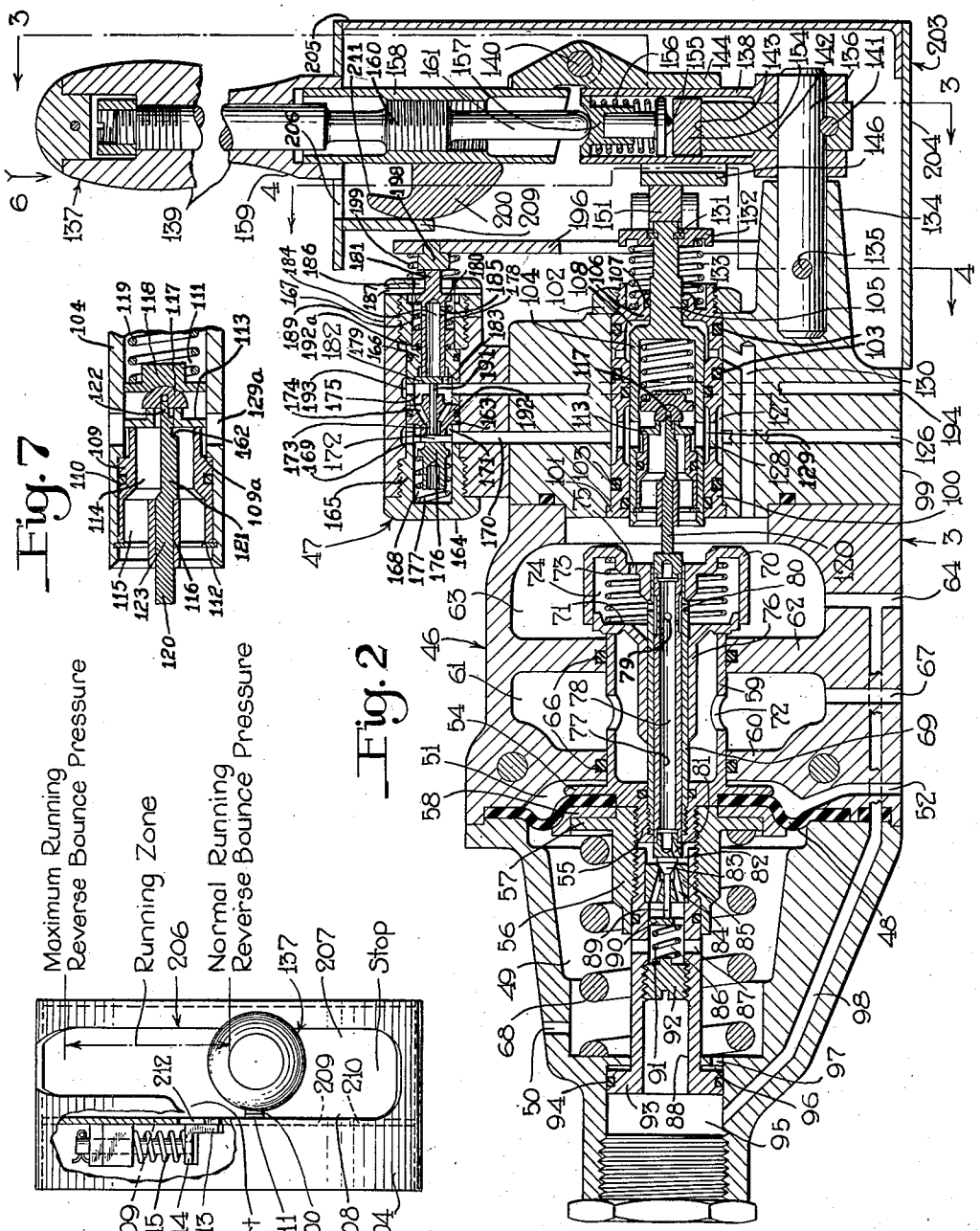


Fig. 2

Fig. 6

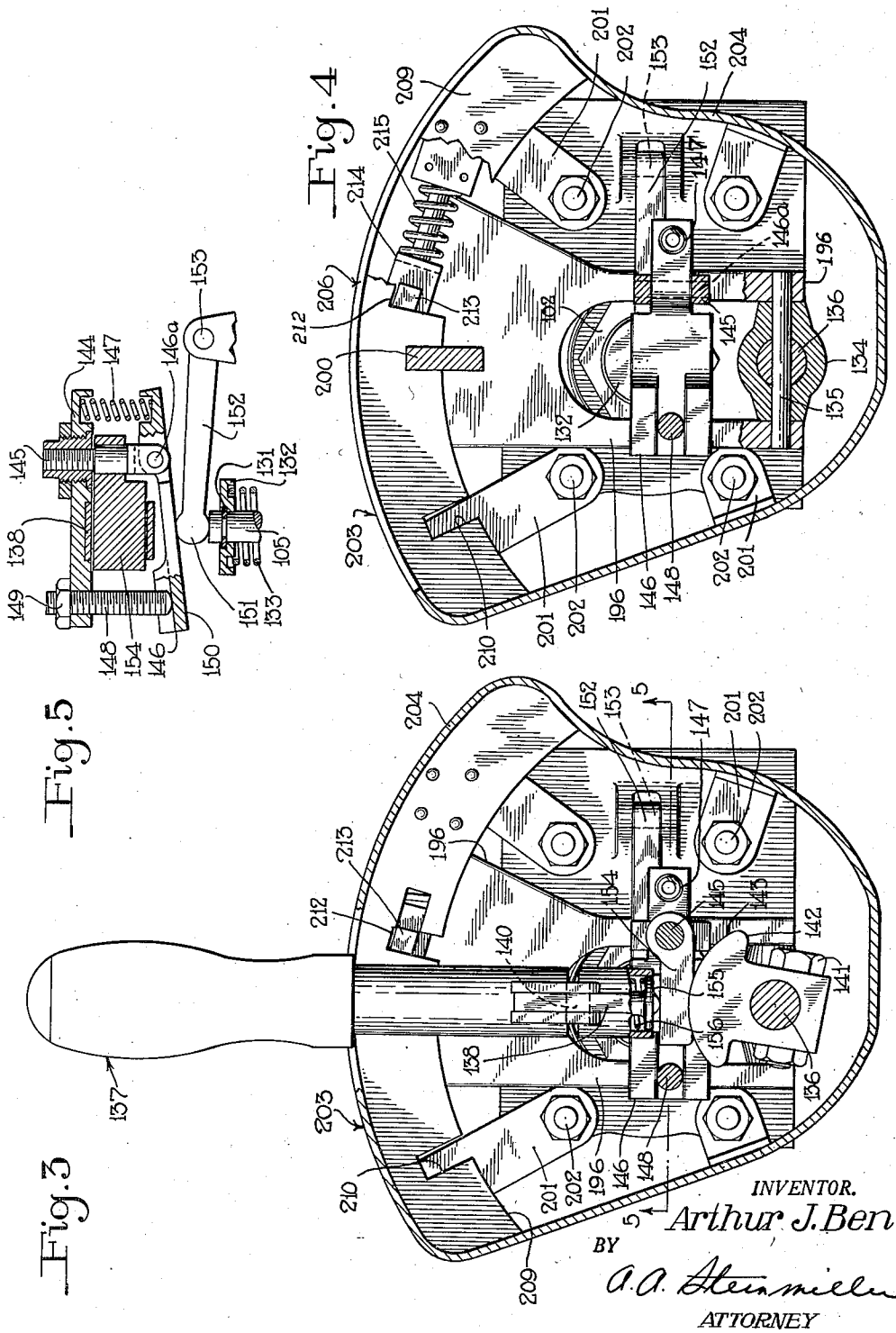
Fig. 7

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FLUID PRESSURE CONTROL APPARATUS FOR FREE PISTON MACHINES

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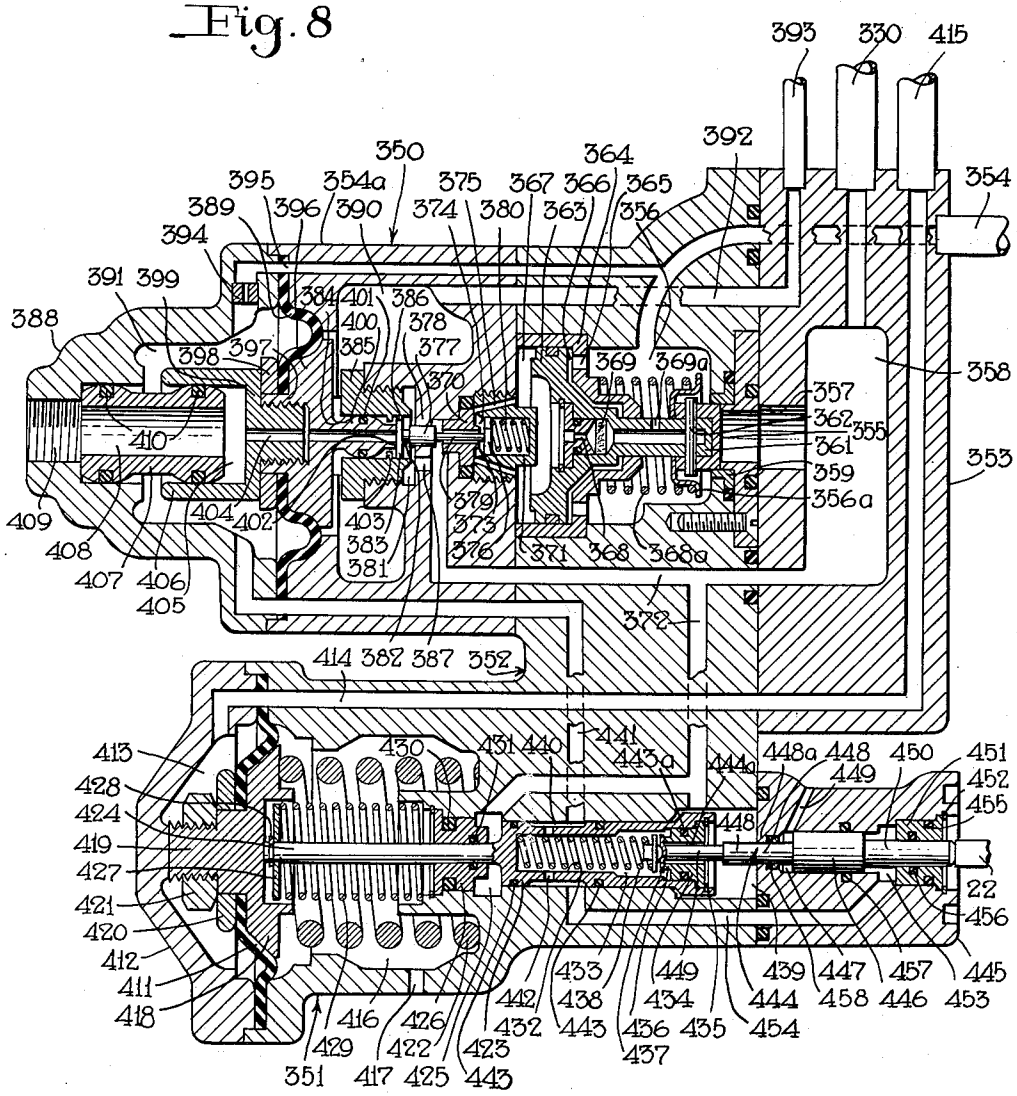


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Fig. 8



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FLUID PRESSURE CONTROL APPARATUS FOR FREE PISTON MACHINES

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Application July 22, 1947, Serial No. 762,771

38 Claims. (Cl. 60—14)

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This invention relates to control apparatus for free piston machines, particularly of the gas generator type, embodying two oppositely arranged motor operated air compressor portions each embodying an internal combustion operated power piston and a coaxially arranged and rigidly connected air compressor piston operative by said power piston to compress air for scavenging and feed of the motor part of the machine and in which the mixture of the hot gases of combustion and of the excess of scavenger air discharged from the motor part of the machine form together generated motive gas which may be employed to perform mechanical work as by expansion in a turbine.

In Patent No. 2,406,037 issued on August 20, 1946, to R. P. Ramsey, there is disclosed a free piston machine of this general type, and one object of the invention is the provision of improved means for controlling starting and/or running of such a machine.

The machine disclosed in the Ramsey patent embodies two oppositely and coaxially arranged motor compressor units each embodying a piston assembly comprising a power piston, an air compressor piston and a direct bounce piston. Between the two power pistons is a power or combustion chamber into which fuel is adapted to be injected for compression ignition for driving said pistons apart. At the outer face of each air compressor piston is an air compressing chamber and said piston is operative by the respective power piston to compress air from said chamber into a scavenger receiver for the purpose above set forth. At the outer face of each direct bounce piston is what may be called a direct bounce chamber in which air is adapted to be compressed upon the air compressing stroke of the respective power piston to provide energy for returning the piston assembly, following scavenging, to its inner position preceding another power stroke. At the inner face of each air compressor piston is what may be called a reverse bounce chamber which is employed in connection with starting the machine and in which the amount of air is arranged to be varied for regulating, in addition to the usual regulation resulting from variations in fuel supply, frequency of reciprocation of the piston assemblies. The regulation of fuel supply to the machine forms no part of the present invention.

Another object of the invention is the provision of improved means controlled by pressure of air in the scavenger receiver and the stroke of the piston assemblies for automatically regulating the

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amount of air in the direct bounce chambers and thereby the energy thereof to return said assemblies in the direction of their inner dead points or firing positions, as required to maintain an output of motive gas corresponding to a normal consumption thereof.

Another object of the invention is the provision of improved means for regulating the amount of air in the reverse bounce chambers for regulating frequency of reciprocation of the piston assemblies.

Another object of the invention is the provision of improved control apparatus for a machine such as the gas generator above mentioned embodying a single operator's control device for controlling starting thereof and for regulating the amount of air in the reverse bounce chambers to control the frequency of operation of the piston assemblies, and further embodying a direct bounce governor device automatically operative to control the amount of air in the direct bounce chambers for regulating the stroke of the piston assemblies in the direction of their inner dead points as required to maintain an output of motive gas equal to the normal consumption thereof.

Other objects and advantages will appear from the following more detailed description of the invention.

In the accompanying drawings: Figs. 1–1A, when arranged with the right hand end of Fig. 1 against the left hand end of Fig. 1A, is a diagrammatic view, partly in section and partly in outline, of a control apparatus embodying the invention; Fig. 2 is a sectional or diagrammatic view, mainly in section, of an operator's control device shown in elevation in Fig. 1; Figs. 3 and 4 are sectional views taken on the lines 3—3 and 4—4 in Fig. 2; Fig. 5 is a sectional view taken on the line 5—5 in Fig. 3; Fig. 6 is a plan view of a portion of the operator's control device taken in the direction of arrow 6 in Fig. 2; Fig. 7 is a slightly enlarged view of a portion of the operator's control device shown in Fig. 2; Fig. 8 is a diagrammatic sectional view of a so-called direct bounce governor device shown in elevation in Fig. 1, and Fig. 9 is a sectional view of a so-called pick-off valve device shown in elevation in Fig. 1.

GENERAL DESCRIPTION

As shown in the drawings, the reference numeral 1 designates a free piston machine of the gas generator type which may be substantially the same in structure as that disclosed in the aforementioned Ramsey patent, and which is em-

ployed in the present application merely for the purpose of illustrating one use of the invention. According to the invention, I provide control apparatus 2 including a single operator's control device 3 for controlling starting of the gas generator 1 and for manually regulating the amount or quantity of air in reverse bounce chambers of said gas generator, a direct bounce governor 4 for automatically regulating the amount or quantity of air in direct bounce chambers of said generator, and other apparatus to be hereinafter particularly pointed out.

Description of gas generator 1

The gas generator 1 comprises a casing containing two coaxial and oppositely arranged like power pistons 5, 5a between which is provided a power or combustion chamber 6 and which are adapted to cooperate, respectively, when close to the outer end of their strokes, with inlet and outlet ports 7 and 8 for said chamber. The inlet port 7, only one of which is shown in the drawing, is open to a scavenger air receiver 9, while the outlet port 8, only one of which is shown in the drawing, is connected to a delivery pipe 10 for the generated motive gas, which pipe may communicate with the inlet to a gas turbine (not shown). Reference numeral 11 designates a fuel injector nozzle for delivering fuel to the combustion or power chamber 6. The means for regulating the fuel to the injector nozzle 11 are not shown in the drawing since, as before mentioned, the fuel control means constitutes no part of the invention.

Two air compressor pistons 12, 12a are disposed at opposite sides of and rigidly connected to the power pistons 5, 5a, respectively, in coaxial relation therewith. At the inner face of each compressor piston 12, 12a is a reverse bounce chamber 13, the two chambers 13 being in permanent communication through a conduit 14. At the opposite face of each compressor piston 12, 12a is an air compressing chamber 15 having an inlet from atmosphere by way of an inlet valve 16 and having an outlet or discharge past a discharge valve 17 to the scavenger air receiver 9.

Projecting from the outer face of the compressor pistons 12, 12a through the air compressing chambers 15 and into suitable bores in the casing, are respectively, rigidly conected and coaxially arranged direct bounce pistons 18, 18a the outer end of each of which cooperates with the casing to form a direct bounce chamber 19, each direct bounce piston and its chamber 19 constituting a cushion means. The two direct bounce chambers 19 are in permanent communication with each other through a conduit 20. The connection between each direct bounce chamber 19 and the conduit 20 is by way of one or more passages 31 and a chamber 32 in the casing constituting a part of the direct bounce chamber 19. The passages 31 open to chamber 19 a slight distance in from the outer end wall of chamber 19 to provide between said wall and passages a safety, cushion space 33 into which the respective direct bounce piston is adapted to move only in starting.

The piston assembly comprising the power piston 5, air compressor piston 12 and direct bounce piston 18 constitute one power operated air compressing unit, while the other pistons 5a, 12a and 18a constitute a piston assembly of another, identical but oppositely arranged air compressing unit, and the two assemblies are connected together for symmetrical movement by any suitable synchronizing mechanism such as two oppositely arranged toothed racks 21 and 22 connected at one end to the air compressing pistons 12, 12a, respectively, and operatively connected to each other by a meshing pinion 23 arranged to turn on a fixed axis.

One or more starting valve devices 24 are associated with the casing for each reverse bounce chamber 13, each starting valve device comprising a vent valve 25 arranged to open inwardly of said chamber for establishing a vent from said chamber to atmosphere by way of a passage 26. A piston 27 connected to valve 25 is arranged to be operated by fluid under pressure in a chamber 28 to open said valve. A spring 29 acts on piston 27 to close valve 25 when fluid under pressure is released from chamber 28. The chambers 28 in all of the starting valve devices 24 are connected to a common control pipe 30.

The gas generator 1, thus far described, and constituting no part of the present invention, is adapted to operate as follows. Starting with the two piston assemblies in the position in which they are shown in the drawing, fluid under pressure will be supplied to the reverse bounce chambers 13 at a pressure sufficient to move said piston assemblies apart to their outermost end positions in which the inlet and exhaust ports 7 and 8, respectively, to the power chamber 6 are open and the outer ends of the direct bounce pistons 18, 18a are disposed in the respective safety spaces 33 in substantial contact with the end walls of chambers 19. The two chambers 32 will then be charged with fluid at suitable pressure which will become effective in the safety spaces 33 over the outer ends of the two direct bounce pistons 18, 18a, following which, the vent valves 25 of the several starting valve devices 24 will be simultaneously opened to establish large vent openings from the reverse bounce chambers 13. The pressure in the reverse bounce chambers 13 will then suddenly reduce and permit the pressure of fluid in safety spaces 33 and chambers 32 to expand into the direct bounce chambers 19 and actuate the direct bounce pistons 18, 18a to drive the two piston assemblies toward each other; the power pistons 5, 5a first closing communication between power chamber 6 and the inlet and outlet ports 7 and 8 and then compressing the air between said pistons in said power chamber. As the power pistons 5, 5a approach their inner dead point, fuel will be introduced through the injector nozzle 11 into the combustion space 6 and then by compression said fuel will be ignited and the expansion of the combustion products in said chamber will stop further inward movement of said piston assemblies and drive said piston assemblies apart, a portion of the energy thus imparted to the piston assemblies being absorbed by recompression of the air in the direct bounce chambers 19.

On the inward stroke of the piston assemblies air will be drawn into the air compressing chambers 15 past the inlet valves 16, while upon the succeeding power stroke the energy not employed for recompressing the air in the direct bounce chambers 19, will compress the air from the air compressing chambers 15 past the discharge valves 17 into the scavenger air receiver 9.

Finally, the power piston 5 will uncover the outlet port 8 and a little later the piston 5a will uncover the inlet port 7 from the scavenger air receiver 9, and air from said receiver will then sweep through the combustion or power chamber 6 to remove the products of combustion therefrom

and to fill said chamber with fresh air from the scavenger receiver 9. It will be apparent that upon starting the generator 1, the air in the scavenger receiver 9 for scavenging the combustion chamber 6 will be only slightly in excess of atmospheric pressure.

At the completion of the power stroke of the two piston assemblies, the energy of the compressed air in the direct bounce chambers 19 will drive the two piston assemblies toward each other again and the cycle of operation, above described, will then be repeated.

In starting and during a warming-up period for the generator 1, the delivery pipe 10 will usually be open directly to atmosphere during which time there will be no material increase in pressure in the scavenger receiver 9, but when the atmospheric connection is closed and the motive gas discharged from the generator is directed to the turbine, the continued operation of the generator will build up a pressure in the scavenger receiver and the pressure of the discharged motive gas will correspondingly increase to that desired.

As the pressure of air compressed into the scavenger receiver increases, a proportional amount of energy will be retained at the end of the air compressing stroke in the air compressing chambers 15 by the compressed air in the clearance space at the outer faces of the compressor pistons 12, which energy will coact with that of the compressed air in the direct bounce chambers 19 to urge the piston assemblies toward their inner dead points or firing position. At the same time, however, the pressure of the fresh air charge in the power or combustion space 6, at the time the power pistons 5, 5a close the outlet and inlet ports 8 and 7, respectively, will increase with scavenger air pressure and provide an increased force opposing such inward movement. Further, the vent valves 25 will close at a certain position of the initial inward stroke of the piston assemblies in starting, as will hereinafter be described, so as to provide in the reverse bounce chambers 13 a certain pressure, at the inner dead points of said assemblies, necessary to prevent stalling of the generator in starting, but which also will oppose such inward movement.

Now it is desirable to vary the energy of the air in the direct bounce chambers 19 with respect to the opposing and coacting pressures just described in such a manner as to cause each piston assembly to move to an inner dead point corresponding to the pressure in the scavenger receiver 9, and to permit movement to an outer dead point, short of the respective bounce pistons 18, 18a covering the passages 31 and entering the safety spaces 33; the outward stroke corresponding to the amount of fuel being supplied to the generator. In other words, if the pressure of air in the scavenger receiver 9 reduces, due to increased use of motive gas, it is desirable to increase the amount of air in and thereby the energy of the direct bounce chambers 19, so as to move in the inner dead point of each piston assembly, and to at the same time permit a moving out of the outer dead point of said assembly due to the usual resulting increase in fuel supply, for in turn increasing the output of compressed air in proportion substantially to the reduction in pressure of the motive gas resulting from increased consumption thereof. On the other hand, as the pressure of the motive gas is restored, it is desirable to reduce the amount of air in and thereby the energy of the direct bounce chambers 19 in proportion, to correspondingly reduce the stroke of the piston assemblies in both directions for proportionately reducing the output of compressed air.

It will therefore be seen that by suitable adjustment of the amount of air in the direct bounce chambers 19 according to the pressure of air in the scavenger receiver 9, the stroke of the piston assemblies in both directions can be regulated as desired, and, in accordance with the invention, this is automatically accomplished by the direct bounce governor 4, as will hereinafter be described.

It is also desirable in case of greater than a normal use of motive gas delivered by the generator 1 to increase the output thereof over that obtained by a maximum amount of fuel and this may be accomplished by increasing the amount of air in the reverse bounce chambers 13 by suitable adjustment of the operator's control device 3, as will be later described.

Description of control apparatus 2

The control apparatus 2 comprises a bracket 34 upon which is mounted the operator's control device 3, as well as starting control mechanism including a shuttle or transfer valve device 325, a direct bounce chamber supply valve device 35, a feed valve device 36, a sequence valve device 37, a vent valve device 38, a dump supply valve device 39, a dump exhaust valve device 40, three check valves 41, 42 and 43, and an adjustable choke 44. A sequence olume 45 is provided in a casing part attached to one end of bracket 34.

The operator's control device 3 comprises a reverse bounce chamber governor portion 46 and a starting valve portion or device 47.

The governor portion 46 comprises a casing containing a flexible diaphragm 48 subject on one side to atmospheric pressure in a chamber 49 which is open to atmosphere through a passage 50. At the opposite side of diaphragm 48 is a control chamber 51 open through a pipe 52 and pick-off valve device 53 to pipe 14 connecting together the reverse bounce chambers 13.

A diaphragm follower 54 contained in chamber 51 and engaging one side of diaphragm 48 has a stud portion 55 extending from one side thereof centrally through said diaphragm and secured by screw-threaded engagement to a sleeve 56 disposed in chamber 49. The sleeve 56 is provided at one end with an annular collar 57 engaging and urging a follower 58 against the opposite side of diaphragm 48 for securely clamping the central portion of said diaphragm between said follower and the follower 54.

A sleeve 59 projects from the opposite side of diaphragm follower 54 through a bore in a partition wall 60 separating chamber 51 from a chamber 61 and thence through another partition wall 62 separating chamber 61 from a chamber 63 which is open through a passage 64 and a pipe 65 to pipe 14 connecting the reverse bounce chambers 13. Sealing rings 66 provided in the partition walls 60 and 62 have sealing and sliding contact with the sleeve 59 for preventing leakage of fluid under pressure from chambers 51 and 63 to chamber 61 which latter chamber is open to atmosphere through a passage 67. A delivery pressure, regulating spring 68 contained in chamber 49 acts on the diaphragm 48 for urging it in the direction of partition wall 60.

A post 69 secured at one end to the diaphragm follower 54 extends centrally through the sleeve

59 to a point in chamber 63 beyond the end of said sleeve, while secured to the opposite end of said post in said chamber is the closed end of a cylinder 70 the opposite open end of which is disposed adjacent and in coaxial relation with the open end of sleeve 59. Slidably mounted in cylinder 70 is a fluid pressure release valve 71 arranged to cooperate with the end of sleeve 59, constituting a seat for said valve, to control communication between chamber 63 and the interior of sleeve 59 which is open through one or more ports 72 in said sleeve to the atmospheric chamber 61. A spring 73 contained in a chamber 74 formed between valve 71 and the closed end of cylinder 70 acts on said valve urging it toward its seat. Chamber 74 is open through a small port 75 in the closed end of cylinder 70 to chamber 63. The valve 71 has a stem 76 slidably mounted on the post 69.

The post 69 has a through axial bore and slidably mounted in this bore is a plunger 77 having an axial bore 78 closed at opposite ends of the plunger. Near one end the plunger 77 has one or more radial ports 79 establishing a constantly open communication between bore 78 and one or more radial ports 80 provided in the post 69 and opening to chamber 74. Near the opposite end the plunger 77 has one or more ports 81 connecting said bore to a release pilot valve chamber 82, it being therefore noted that chamber 82 and the release valve chamber 74 are in constant communication. A pilot release valve 83 contained in chamber 82 is arranged to control communication between said chamber and the atmospheric chamber 49 by way of a plurality of ports 84 in a seat member 85, a chamber 86 and a plurality of ports 87 in an equalizing member 88. The pilot valve 83 has a stem 89 extending through a suitable guide bore in seat member 85 into chamber 86 wherein it engages one side of an apertured spring follower 90. One end of a precompressed spring 91 contained in chamber 86 engages the opposite side of follower 90, while the opposite end of said spring is supported on a nut 92 adjustably mounted in the equalizing member 88. This spring is provided for unseating the release pilot valve 83 and for concurrently shifting the plunger 77 axially in post 69. Movement of plunger 77 in the opposite direction is adapted to seat the pilot release valve 83.

The equalizing member 88 has one end connected to the sleeve 56 which is secured to the diaphragm 48 for movement therewith. A balancing piston 93 is formed on the opposite end of equalizing member 88 and carries a sealing ring 94 having sealing and sliding contact with the wall of a bore in the casing, said piston separating a pressure chamber 95 at one side from a non-pressure chamber 96 at the opposite side which latter chamber is open to the atmospheric chamber 49 as by way of a passage 97. Chamber 95 is in constant communication through a passage 98 and passage 64 with the chamber 63. The diameter of the balance piston 93 is the same as that of sleeve 59 in chamber 63, so as to provide surfaces of said piston and of the release valve 71, when seated, of equal areas subject opposingly to pressures of fluid in chambers 95 and 63, 74, whereby oscillation or fluctuations in pressure in passages 64, and thereby in said chambers will not influence positioning of said parts and of the interconnecting parts above described.

The end of chamber 63 opposite that through which extends the sleeve 59 is closed by a casing part 99 having a through bore and mounted in said bore in coaxial relation to said sleeve is a bushing 100. This bushing has at the end adjacent chamber 63 an annular stop collar 101 seating in a recess in the casing portion 99, while engaging the opposite and outer side of the casing part and having screw-threaded engagement with an extended part of said bushing is a securing nut 102 for holding the bushing in place. A number of sealing rings 103 spaced from each other are carried by the bushing 100 and have sealing contact with the wall of the bore in which said bushing is disposed to prevent leakage of fluid under pressure between chamber 63 and various passages to be hereinafter mentioned.

Slidably mounted in the bushing 100 is a plunger 104 having at one end a stem 105 of smaller diameter extending through a bore in an inwardly extending collar 106 provided on the bushing 100 adjacent its outer end. A sealing ring 107 carried by collar 106 engages stem 105 for preventing leakage of fluid under pressure along said stem from a balancing chamber 108 formed between the outer end of plunger 104 and the adjacent surface of collar 106. The plunger 104 has an axial bore closed at the end adjacent the stem 105, while the opposite end is open to chamber 63, and disposed in this bore against a shoulder 109a is a supply valve seat member 109. The member 109 is provided with a sealing ring 110 engaging the wall of the bore for preventing leakage of fluid under pressure from a supply pressure or supply valve chamber 111 formed at the inner end of member 109 within said bore past said member to chamber 63. The seat member 109 is supported in place in plunger 104 by a ring 112 disposed in a recess in said plunger and engaged by the outer end of said seat member.

A main supply valve 113 contained in the supply valve chamber 111 is provided for seating engagement with the adjacent end of seat member 109 for controlling flow of fluid under pressure from said chamber to chamber 63 by way of an axial bore 114 extending part way through said member and thence through a plurality of ports 115 provided around a central integral section 116 of said member. The supply valve 113 is provided with an axial bore and surrounding said bore and extending into chamber 111 is a valve seat arranged to be engaged by a supply pilot valve 117 contained in said chamber. The pilot valve 117 is engaged by a follower 118 subject to pressure of a spring 119 for seating said pilot valve and in turn the supply valve 113. A pin 120 having a fluted portion 121 disposed within bore 114 in the seat member 109 has a coextensive fluted portion 122 of smaller diameter extending through the axial bore in the supply valve 113 into engagement with the supply pilot valve 117, a shoulder 162 being formed at the junction of the larger and smaller fluted portions. This shoulder 162 is spaced from the supply valve 113 when the pilot valve 117 is seated thereon but is adapted to engage and unseat said supply valve subsequent to unseating said pilot valve. The pin 120 has a bearing part 123 extending in the opposite direction from the fluted portions thereof through and in sliding contact with the axial bore in the integral section 116 of the seat member 109 into chamber 63 for engagement with the adjacent end of plunger 77.

The supply valve chamber 111 is adapted to be constantly supplied with fluid at a desired reduced pressure, from a feed valve device 124

through a pipe 125, a passage 126 extending through the bracket 34 and connected to a cavity 127 surrounding the bushing 100 and thence through one or more ports 128 in said bushing, an annular chamber 129 formed between said bushing and plunger 104 and encircling the latter, and one or more radial ports 129a in said plunger opening to chamber 111.

The chamber 63 at one end of plunger 104 is open through a passage 130 to chamber 108 at the opposite end for constantly equalizing pressures of fluid therein to minimize the force required to move said plunger in the direction of chamber 63 when the latter chamber is supplied with fluid under pressure, as will be later described. Secured by a ring 131 to the plunger stem 105 adjacent the outer end thereof is a spring seat 132 and interposed between said seat and the bushing collar 106 is a bias spring 133 acting constantly to urge the plunger 104 outwardly of the casing part 99.

At one side of the plunger stem 105 the casing part 99 has an integrally formed projecting arm 134 in which there is secured by a pin 135 a shaft 136 extending parallel to the axis of said stem, and mounted to turn on this shaft in a plane at right angles to the axis of said shaft and stem is an operator's control lever 137.

The lever 137 comprises an inner journaled part 138 mounted on shaft 136 and a hand grip part 139 hingedly connected together by a pin 140 to permit movement of the latter part relative to the former part in a plane only in the direction toward and away from the casing part 99.

The end of the journaled part 138 is bifurcated, and secured by a bolt 141 to the shaft 136 is an element 142 disposed between the two journaled parts of the lever 137 for holding said lever on said shaft. The element 142 has an arcuate surface 143 concentric with the axis of said shaft 136. Secured to the side of the journaled part 138 opposite to and extending at right angles to the axis of the plunger stem 105 is a plate 144. Secured to plate 144 at one side of the journaled part 138 is a cam fulcrum element 145 to which is fulcrumed on a pin 146a one end of a rectangular like cam element 146 disposed parallel to plate 144 at the opposite side of the journaled part 138 of the lever. A spring 147 interposed between the plate 144 and cam element 146 urges the cam element about its fulcrum pin 146a in a direction against an adjusting screw 148 adjustably carried by the plate 144 at the opposite side of said lever. A lock nut 149 on screw 148 is provided for contact with plate 144 to lock the screw 148 in an adjusted position.

The cam element 146 has a cam surface 150 for engaging one side of a follower 151 the opposite side of which contacts the plunger stem 105, the parts being so arranged that with the lever 137 in an extreme left-hand position, as viewed in Fig. 3 and to be hereinafter defined, the spring 133 will urge the plunger 104 into substantial contact with the bushing collar 106, while upon movement of said lever out of this position in a clockwise direction, as viewed in Fig. 3, said cam element will displace said plunger in the direction of chamber 63 a distance proportional to the degree of such movement. The follower 151 is formed on one end of an arm 152 the opposite end of which is fulcrumed on a pin 153 carried in the casing part 99.

Fulcrumed at one end on the cam fulcrum element 145 is a friction locking shoe 154 having a part disposed within the journaled part 138 of the lever and provided in one side with a concave surface for frictionally engaging the arcuate surface 143 of the element 142. Engaging the opposite side of shoe 154 is a pressure element 155 engaged by one end of a spring 156 the opposite end of which is engaged by a follower 157 slidably mounted in the part 138 of lever 137.

The hand grip part 139 of the operator's control lever 137 comprises an inner part 158 connected to the hinge pin 140 and an outer grip part 159 secured to and carried by a screw 160 having screw-threaded connection with the inner part 158. The screw 160 is provided with an extension 161 the end of which engages the follower 157. Turning the grip part 159 and screw 160 into the lever 137 will actuate the follower 157 to compress spring 156 and thereby actuate pressure element 155 against the friction shoe 154 to in turn press said shoe against the arcuate surface 143 of the fixed element 142 for holding the operator's control lever in a desired operating position. Turning the grip part 159 of the operator's control lever 137 in the opposite direction will release the force of spring 156 on shoe 154 and thereby the force of said shoe against element 142 to permit manual movement of the operator's control lever 137, as desired.

The starting valve portion 47 of the operator's control device comprises a casing mounted on the casing part 99 of said device at one side of the operator's control lever 137; said casing having a through opening in which is slidably mounted a supply valve seat member 163. A cap 164 secured to the end of the casing opposite the operator's control lever 137 has a sleeve 165 extending into the opening in the casing with its end engaging one end of the seat member 163. The opposite end of the seat member 163 is engaged by one end of a bushing 166 having a screw-threaded connection with the casing and extending from the opposite end thereof, and mounted over the extending portion of the bushing 166 is a cap 167 screwed onto the bushing into contact with the casing. Between the seat member 163 and the cap 164 is a supply valve chamber 168 open through one or more radial ports in the bushing 165 to an annular cavity 169 encircling said bushing and connected by a passage 170 to cavity 127 which is constantly supplied with fluid under pressure from the feed valve device 124, as above described. The seat member 163 is provided in chamber 168 with an annular seat rib 171 arranged for contact by a fluid pressure supply valve 172 for controlling communication between said chamber and a cavity 173 formed in the seat member 163 within said seat rib. The cavity 173 is in turn open through one or more ports 174 in the seat member 163 to a release valve chamber 175 formed at the opposite side of said seat member therebetween and the adjacent end of the bushing 166. The supply valve 172 is engaged on the side opposite the seat rib 171 by a spring follower 176 subject to the pressure of a spring 177 contained in the sleeve portion 165 of cap 164, said spring constantly urging said supply valve in the direction of its seat.

The bushing 166 has adjacent the release valve chamber 175 an axial bore open at one end to said chamber and at its opposite end to a counterbore 178, and slidably mounted in this axial bore and extending into the release valve chamber 175 is a hollow stem 179. The stem 179 has an annular collar 180 disposed in the counterbore 178, and projecting from said collar through

a suitable bore in the cap 167 is an operating stem 181. A fluid pressure release valve 182 of the disc type contained in chamber 175 is arranged to be engaged by the adjacent end of the hollow stem 179 for closing communication between said chamber and atmosphere by way of one or more ports 183 provided through said valve outside of its seat on the end of said stem, thence through an axial bore 184 and one or more radial bores 185 in said stem to the counterbore 178 and thence past the loosely fitting collar 180 to a chamber 186 which is connected to atmosphere through one or more radial ports 187 in the cap 167. A spring 189 encircling the hollow stem 179 acts on the collar 180 thereof for urging said stem out of contact with the release valve 182, it being noted that the inner end of bushing 166 is disposed for contact by the release valve for limiting movement thereof in the direction of said stem.

The supply valve seat member 163 is provided with an axial bore of smaller diameter than cavity 173 and slidably mounted in this bore is an operating pin 191 the opposite ends of which engage respectively the supply valve 172 and the release valve 182. A suitable ring seal 192 carried by the supply valve seat member 163 and having sealing contact with the wall of the bore in the casing is provided for preventing leakage of fluid under pressure from the supply valve chamber 168 to the release valve chamber 175. A similar ring 192a provided in the bushing 166 has sealing and sliding contact with the outer surface of the hollow stem 179 for preventing leakage of fluid under pressure from the release valve chamber 175 along said stem to the counterbore 178 and thence to atmosphere. The release valve chamber 175 is open through one or more radial ports 193 to a passage 194 which is connected to a passage 195 in the bracket 34, for reasons to be later described.

With the parts of the starting valve portion 47 in the position in which they are shown in the drawing it will be noted that the supply valve 172 is closed to prevent supply of fluid under pressure to the release valve chamber 175 and thence to passage 195 in the bracket 34 while the release valve 182 is unseated opening chamber 175 and passage 195 to atmosphere. However upon movement of the operating stem 181 into the casing the hollow stem 179 will first move into contact with the fluid pressure release valve 182 to close communication between the release valve chamber 175 and atmosphere, following which, further movement of said stem acting through said valve and the operating pin 191 will open the fluid pressure supply valve 172. When the supply valve 172 is open fluid under pressure provided by the feed valve device 124 in the supply valve chamber 168 will flow therefrom to the release valve chamber 175 and thence to passage 195 in the bracket 34. Upon removal of force on the operating stem 181 spring 189 will return the hollow stem 179 to the position in which it is shown in the drawing. As the stem 179 is thus moved, spring 177 will move the supply valve 172, the operating pin 191 and the release valve 182 with said stem until the supply valve 172 seats to prevent further flow of fluid under pressure to the release valve chamber 175. After the supply valve seats the release valve 182 will contact shoulder 190 in the casing following which further movement of the hollow stem 179 by spring 189 will open communication between the release valve chamber 175 and atmosphere for releasing fluid under pressure from the passage 195 in the bracket.

A rockable bail 196 is provided for controlling or effecting inward movement of the operating stem 181 of the starting valve portion 47. One end of this bail is fulcrumed on the pin 135 extending through the shaft 136 carrying the operator's control lever 137 and through the arm 134 projecting from the casing and in which said shaft is mounted, it being noted that said pin also secures said shaft to said arm. Near the opposite end of the bail 196 a button 198 is secured thereto for contact with the operating stem 181 and a spring 199 encircling said button is supported at one end on the starting valve portion 47 while its opposite end bears against said bail for urging the button 198 in the direction away from the operating stem 181. The operator's control lever 137 is provided with an operating element 200 on the hand grip portion 139 adapted upon movement of said hand grip portion about the hinge pin 140 in the direction of bail 196 to engage said bail and actuate same to push the operating stem 181 into the starting valve device 47. The bail 196 can thus be operated by the operator's control lever 137 only in a certain portion of its operating zone, as will now be described.

Mounted over the operator's control lever 137 and suitably secured, as by arms 201 and studs 202, to the casing part 99 is a cover 203 comprising a side portion 204 the outer end of which may be closed by cover 205 secured to said side portion. Through the side portion 204 there is provided a slot 206 through which the operator's control lever 137 projects for confining movement of said lever to a chosen path and degree. The slot 206 comprises a relatively long portion 207 into one side of which opens a shorter portion 208. The longer portion 207 of the slot is arranged to permit movement of the operator's control lever 137 about the shaft 136 in a plane in which it is out of contact with bail 196 from a "Stop" position at one end of the longer portion of the slot to a "Maximum Running Reverse Bounce Pressure" position at the opposite end. The shorter portion 208 is arranged to permit movement of the hand grip portion of the operator's control lever 137 about the hinge pin 140 for depressing the bail 196, and one end of this shorter portion 208 of the slot 206 is aligned with the end of the longer portion 207 adjacent the "Stop" position therein, it being noted that in this shorter portion the lever 137 is also movable in the plane above mentioned, but to a lesser degree than in the longer portion 207 of the slot 206.

It is desirable that the operator's control lever 137 enter the short portion 208 of the slot only at the end thereof adjacent the "Stop" position of said lever. At the opposite end of the shorter portion 208 is a "Start" position and it is desirable that the lever be returned to the longer portion 207 of the slot only from this "Start" position. To insure this path of movement of the operator's control lever 137 a ledge 209 projects from the side portion 204 of the cover into the interior thereof for contact by the operating element 200, associated with the operator's control lever, in the zone of movement between the "Stop" and "Start" positions above mentioned. The ledge 209 is provided adjacent one end with a slot 210 adapted to permit movement of the element 200 associated with the operator's control lever from one side to the other of the ledge to permit movement of said lever from the "Stop"

position into the short portion 208 of the slot 206 for operating the starting valve device 47. The element 200 has a hook 211 arranged to engage the side of ledge 209 opposite that adjacent the operator's control lever when said lever is moved into the short portion 208 of the slot to prevent return of said lever to the long portion of the slot until said lever is moved to the "Start" position where a slot 212 is provided through said ledge to permit the element 200 to return to the opposite side of said ledge in which the lever will be in the long portion 207 of the slot.

When the operator's control lever 137 is returned from the short portion 208 of the slot 206 into the long portion 207 thereof it will be in what may be called a "Normal Running Reverse Bounce Pressure" position and during running of the gas generator may be adjusted from this position in a direction away from the "Stop" position to any position in a "Running Zone" up to and including a "Maximum Running Reverse Bounce Pressure" position, as required to regulate the frequency of operation of the gas generator, as will be later described. While the gas generator 1 is operating under normal conditions of motive gas consumption the operator's control lever 137 will however occupy the "Normal Running Reverse Bounce Pressure" position.

It is desirable to prevent unintentional movement of the operator's lever 137 from the long portion 207 of the slot 206 back through the slot 212 to the "Start" position, and this is prevented by the provision of a slidable trap 213 which is arranged to close the slot 212 immediately upon movement of said lever out of "Start" position to the "Normal Running Reverse Bounce Pressure" position and to then provide a substantially flush bridge across slot 212 for movement of the lever in the long portion 207 of slot 206 during running of the generator. The trap 213 has a lug 214 projecting therefrom in a direction away from the ledge 209 for engagement by the operating element 200 of the operator's control lever 137 as it is moved to "Start" position through the short portion 208 of the slot 206 for moving the trap out of closing relation with slot 212 by the time said lever obtains said "Start" position, whereby said lever may then be moved through the slot 212 to the long portion 207 of the slot 206 when desired. When the element 200 passes through the slot 212 a spring 215 acting on the trap 213 promptly urges it to the position in which the slot 212 is closed. It will thus be seen that the operator's control lever 137 can only be moved to "Start" position in the short portion 208 of the slot 206 from the "Stop" position in the longer portion 207 and upon return to said longer portion from the "Start" position, unintentional return movement to the latter position through the slot 212 is positively prevented.

The feed valve device 124, above mentioned, may be of any conventional type operable to provide in pipe 125 fluid at a constant chosen reduced pressure, such as three hundred pounds, from a supply pipe 216, which may be charged with fluid at a pressure such as one thousand pounds.

The direct bounce supply valve device 35 is arranged to control supply of fluid under pressure from passage 126 in the bracket 34 to the feed valve device 36, the passage 126 being supplied with fluid under pressure from the feed valve device 124 by way of pipe 125.

The direct balance supply valve device 35 comprises a casing removably mounted on the bracket 34 and containing a flexible diaphragm 219 clamped around its edge in the casing and cooperating therewith to form at one side a non-pressure chamber 220 which is open to atmosphere as by way of a vent passage 221. Engaging the opposite side of the diaphragm 219 is a follower 222 having a stud 223 extending centrally through the diaphragm and through a follower 224 contained in chamber 220 and engaging the opposite side of the diaphragm, and these two followers are rigidly secured to opposite sides of the diaphragm by a nut 225 provided on the stud 223 and engaging the follower 224.

The diaphragm follower 222 is provided in the face opposite that engaging the diaphragm with a recess in which is disposed a sealing ring constituting a valve 226 arranged to seal against an annular seat rib 227 formed in the casing. Encircling the rib 227 is a pressure chamber 228 arranged on the side of diaphragm 219 opposite to the non-pressure chamber 220 and open to atmosphere through a small leak port 228a, and within said rib is a pressure chamber 229 which is in permanent communication through a passage 230 and a pipe 231 with a timing valve device 232 associated with the gas generator.

The direct balance supply valve device 35 further comprises a valve 235, contained in a chamber 236 open to the fluid pressure supply passage 126, and arranged to control communication between said chamber and a passage 237 leading to the feed valve device 36. The supply valve 235 is operatively connected to a stem 238 which extends through a bore in a partition wall 239 separating chamber 236 from chamber 229, and thence centrally through the latter chamber and an axial bore provided in the stud 223 and associated follower 222. The stem 238 extends into chamber 220 above the stud 223 and carries a ring 240 for engaging the end of said stud whereby deflection of the diaphragm 219 in the direction of the non-pressure chamber 220 will open the supply valve 235. One end of a control spring 241 contained in chamber 220 engages the follower 224 while its opposite end is supported on a follower 242 engaged by an adjusting screw 243 having screw-threaded engagement with the casing whereby the pressure of said spring against the diaphragm 219 may be regulated. The stem 238 carries a sealing ring 244 having sealing and sliding contact with the wall of the bore through partition 239 for preventing leakage of fluid under pressure between chambers 236 and 229.

The timing valve device 232 associated with the gas generator 1 may be identical in construction to the starting valve device 47 associated with the operator's control device 3, the pipe 231 from the direct bounce supply valve device 35 being connected to the release valve chamber 175 therein, while connected to the supply valve chamber 168 is a pipe 233 which opens to pipe 14 connecting the reverse bounce chambers 13 in said generator. The timing valve device 232 is so associated with the gas generator 1 that the supply valve 172 therein will be open and the release valve 182 closed when the direct bounce pistons 18 and 18a are disposed in the safety spaces 33 at the outer end of the reverse balance chambers 19, but when said pistons are out of said chambers said supply valve will be closed and said release valve open. To thus control the timing valve device 232 means, such as a lug 234 may be provided on one of the racks, such as the rack 22 for engaging and operating the operating stem 181 of said timing valve device at the proper time.

The feed valve device 36 may be identical in construction and operation to the feed valve device 124. Passage 237 connected to the feed valve device 36 constitutes a fluid pressure supply passage to said device while the reference numeral 245 designates a delivery passage from said feed valve device, said feed valve device being operative upon supply of fluid under pressure to passage 237 to deliver to passage 245 fluid at a constant reduced pressure, such as one hundred fifty pounds.

The sequence valve device 37 comprises a casing removably mounted on bracket 34 and containing a flexible diaphragm 246 secured around its edge in the casing. At one side of the diaphragm is a chamber 247 open to atmosphere as by way of a passage 248, while engaging the opposite side of said diaphragm is a follower 249. The follower 249 is provided with a stud 250 extending centrally through the diaphragm 246 into chamber 247 and mounted over said stud in the latter chamber is a diaphragm follower 251 and a nut 252 having screw-threaded engagement with said stud and engaging the latter follower for securely clamping the central portion of the diaphragm between said followers.

The casing of the sequence valve device 37 has a chamber 253 open to a passage 254 and containing a valve 255. The valve 255 is double ended, that is, in one position it is adapted to cooperate with a seat 256 in the casing for closing communication between chamber 253 and a passage 257 leading to atmosphere, while opening said chamber through an oppositely arranged valve seat 258 to a chamber 259, which latter chamber is open to passage 195 in the bracket 34. In another position of valve 255 it is arranged to cooperate with seat 258 for closing communication between chambers 253 and 259 and for opening the former chamber to the exhaust passage 257.

The valve 255 is operatively connected to a stem 260 which extends through the communication encircled by valve seat 258 between chambers 253 and 259, and thence through the latter chamber, a partition wall 251 and an axial bore provided through the follower 249 and stud 250. A ring 262 carried by the stem 260 engages the outer face of the diaphragm follower 249 while a similar ring 263 secured to said stem engages the opposite end of stud 250 for connecting said stem to the diaphragm 246 for movement thereby. A sealing ring 264 provided in the stem 260 within the axial bore through stud 250 has sealing contact with the wall of said bore to prevent leakage of fluid under pressure along said stem to the non-pressure chamber 247. A similar sealing ring 265 carried by the stem 260 engages the wall of bore through partition wall 251 for preventing leakage of fluid under pressure between chamber 259 at one side of said wall and a pressure chamber 266 at the opposite side. Chamber 266 is provided within a sealing rib 267 encircling the stem 260 concentrically thereof and arranged for contact by a valve 268 provided in the adjacent face of diaphragm follower 249. Encircling the seat rib 267 is a pressure chamber 269 which is open to atmosphere through a small leak port 269a. The chamber 266 within the seat rib 267 is open to a passage 270 in the bracket. A precompressed spring 271 contained in non-pressure chamber 247 bears at one end against the diaphragm clamping nut 252 while its opposite end is supported on a seat 217 in turn supported on one end of an adjusting screw 218 having screw-threaded engagement with the casing.

The vent valve device 38 comprises a casing containing a piston 272 at one side of which is a non-pressure chamber 273 open to atmosphere through a vent port 274. At the opposite side of piston 272 is a pressure chamber 275 open to passage 195 in the bracket. The piston 272 is provided with an operating stem 276 extending through chamber 275 and a suitable bore in a partition wall 277 separating said chamber from a chamber 278 and thence through a communication 279 into a chamber 280 which is open to a passage 270. Encircling the communication 279 within the chamber 280 is a valve seat 281 arranged for contact by valve 282 for closing communication between said chamber and chamber 278. A spring 283 in chamber 280 acts on valve 282 for urging it to its seated position. A spring 284 contained in chamber 273 and acting on piston 272 is provided for actuating said piston to unseat the valve 282 when pressure chamber 275 is void of fluid pressure. Supply of fluid pressure to chamber 275 is adapted to actuate the piston 272 against spring 284 to permit closing of valve 282 by spring 283.

The dump supply valve device 39 comprises a casing removably mounted on bracket 34 and having a chamber 285 open to a passage 286 and containing a valve 287 arranged to cooperate with a seat 288 for controlling communication between said passage and a passage 289 which is connected by a pipe 290 to pipe 30 leading to the piston chambers 28 in the several starting valve devices 24. The valve 287 is connected to a plunger 291 which is slidably mounted in a partition wall 292 separating chamber 285 at one side of said wall from a chamber 293 at the opposite side. Chamber 293 is open to atmosphere through a vent port 294. A sealing ring 295 carried by the plunger 291 has sealing and sliding engagement with the wall of the bore in partition wall 292 for preventing leakage of fluid under pressure from chamber 285 to chamber 293. The diameter of plunger 291 is substantially the same as that of seat 288 so that with valve 287 engaging said seat and chamber 285 charged with fluid under pressure, in a manner to be later described, the opposing forces developed by said pressure on said valve and plunger will be substantially equal. The plunger 291 is connected to one end of a stem 296 the opposite end of which is connected to a piston 297 one side of which is open to chamber 293. At the opposite side of piston 297 is a pressure chamber 298 open to passage 254. A spring 299 contained in chamber 293 acts on piston 297 for urging same in a direction to unseat valve 287 from its seat 288. A dash pot piston 297a associated with piston 297 is cooperative with the casing to control movement of piston 297 by spring 299.

The dump exhaust valve device 40 comprises a casing removably mounted on the bracket 34 and containing a flexible diaphragm 301 clamped around its edge in the casing. At one side of the diaphragm 301 is a pressure chamber 302 opened to a passage 303 in the bracket, while at the opposite side is a non-pressure chamber 304 opened to atmosphere through a slot 305. A follower 306 contained in chamber 302 and engaging the adjacent face of diaphragm 301 is provided with a stud 307 extending centrally through the diaphragm and through a follower 308 engaging the opposite side of the diaphragm and has screw-threaded engagement with a

combined nut and spring seat 309 which is arranged to clamp the two followers to opposite sides of the diaphragm.

The casing of the dump exhaust valve device 40 is provided with a bore arranged in coaxial relation to diaphragm 301 and opening at one end to the non-pressure chamber 304 and at the opposite end to a chamber 310 which is connected to passage 289 in the bracket, and slidably mounted in this bore is a plunger 311. The plunger 311 is provided on one end of a stem 312 which extends through an axial bore in stud 307 into the pressure chamber 302 wherein a button 313 is provided on the end of said stem for contact by the diaphragm follower 306. A valve 314 contained in chamber 310 is loosely connected to the plunger 311 and is arranged to cooperate with a seat 315 for controlling communication between chamber 310 and a passage 316 in the bracket 34 which passage leads to atmosphere. The diameter of the valve seat 315 is substantially the same as that of plunger 311 whereby with the valve seated and chamber 310 charged with fluid under pressure, in a manner which will be later described, the force acting in a direction to seat said valve will be substantially counterbalanced by the force acting to move the plunger 311 in a direction away from said valve whereby a minimum of force will be required on the stem 312 for opening the valve 314. The end of the casing at the upper end of the bore in which plunger 311 is mounted provides a stop 317 for engagement by the nut 309 to limit movement of the diaphragm 301 in a downwardly direction, the parts being so arranged that a certain amount of this movement will occur after seating of the valve 314 and thus relative thereto. A sealing ring 318 carried by plunger stem 312 and having sealing and sliding contact with the wall of the bore through stud 307 is provided for preventing leakage of fluid under pressure from chamber 302 to the non-pressure chamber 304. A smiliar sealing ring 318*a* carried by plunger 311 has sealing and sliding contact with the wall of the bore in which said plunger operates for preventing leakage of fluid under pressure from chamber 310 to chamber 304. A regulating spring 319 supported at one end on an adjustable seat 320 having screw-threaded engagement with the casing bears at its opposite end against the combined nut and spring seat 309 for opposing movement of diaphragm 301 by pressure of fluid in chamber 302. Encircling the plunger stem 312 and interposed between the plunger 311 and the combined nut and spring seat 309 is a light bias spring 321 for permitting movement of diaphragm 301 relative to valve 314 as before mentioned and for also permitting movement of said valve relative to said diaphragm as will hereinafter be brought out.

The specific structure of the dump valve device 40 is the invention of Donald J. Price and is fully described and claimed in his copending application Serial No. 766,973, filed August 7, 1947, and assigned to the assignee of the present application.

The shuttle or selector valve device 325 comprises a casing removably mounted on the bracket 34 and having a chamber 326 open to a pipe 327 leading to pipe 20 which connects together the two reverse bounce chambers 19 in the gas generator 1. Contained in chamber 326 is a double seating valve 328 arranged in one position to cooperate with a seat 329 for closing communication between pipe 327 and a pipe 330 leading to the direct bounce governor 4, and for at the same time opening communication between pipe 327 and passage 303 in the bracket 34 through a seat 331. In another position, valve 328 is adapted to cooperate with seat 331 for closing communication between chamber 326 and the bracket passage 303 and for opening communication through the valve seat 329 to pipe 330 leading to the direct bounce governor 4. The valve 328 is loosely connected to one end of a stem 332 which extends through the seat 331 and a partition wall 333 into a chamber 334 which may be open to atmosphere by way of a vent port 335. The partition wall 333 separates the atmospheric chamber 334 from the communication with passage 303. A sealing ring 336 carried by the stem 332 has sealing and sliding contact with the wall of the bore through partition wall 333 for preventing leakage of fluid under pressure from passage 303 to the atmospheric chamber 334. Chamber 334 is provided at one side of a piston 337 to which the stem 332 is connected. At the opposite side of piston 337 is a pressure chamber 338 which is open to passage 195. A spring 339 contained in chamber 334 acts on the piston 337 for actuating same, when chamber 338 is open to atmosphere, as will be later described, and thereby the stem 332 to move the valve 328 into contact with seat 331. A dash pot piston 337*a* associated with piston 337 is cooperative with the casing to prevent spring 339 slamming valve 328 against seat 331 with damaging force.

The check valve 41 is provided for preventing flow of fluid under pressure in a direction from passage 303 to a passage 340 and is subject to light pressure of a bias spring 341 which urges it toward its closed position. The check valve 42 is provided for preventing flow of fluid under pressure in the direction from passage 286 to passage 245 and to limit pressure of fluid obtained in passage 286 from passage 245 to a chosen lower degree than in the latter passage, as will be later described. To accomplish these ends the check valve 42 is subject to pressure of a spring 342 for urging it to its closed position with a chosen degree of force. The check valve 43 is provided for preventing flow of fluid under pressure in the direction from passage 270 to passage 303 and is subject to the light seating pressure of a spring 343. It will be noted that the sequence volume 45 is always open to passage 270 in the bracket.

The choke 44 is adjustable to provide a restricted opening between passages 245 and 340 for providing a desired rate of flow of fluid under pressure in the direction of the latter passage, for reasons to be hereinafter described.

A communication may be provided between pipe 231 from the timing valve device 232 and passage 254 in the bracket 34 by way of a check valve 348 contained in said bracket and arranged to prevent flow of fluid under pressure in the direction to said pipe. A spring 349 acts on said check valve 348 for urging it to its closed position.

The pick-off valve device 53 to which pipe 52, connected to the operator's control valve device 3, is connected comprises (Fig. 8) a casing which may be mounted on pipe 14 connecting the reverse bounce chambers 13 in the generator 1 and preferably close to one of said chambers. The casing has a communication between pipe 14 and pipe 52 for permitting flow of fluid under pressure in the direction from the reverse bounce chambers 13 to the latter pipe, a check valve 344 being provided for closing this communication

to prevent reverse flow of fluid under pressure therethrough. A bias spring 345 acts on the check valve 344 for urging it to its closed position. By-passing the check valve 344 is another communication controlled by an adjustable choke valve 346 through which fluid may flow at a restricted rate from pipe 52 to pipe 14. The casing also has a restricted vent passage 347 opening pipe 52 to atmosphere.

The direct bounce governor device 4 comprises a fluid pressure regulating mechanism 350 for controlling the pressure of fluid in the direct bounce chambers 19 of the gas generator 1 and a control portion 351 for controlling operation of said regulating mechanism, said mechanism and control portion comprising a common casing section 352 mounted on a pipe bracket 353 and the said mechanism comprising in addition a casing section 354a mounted on the casing section 352.

The fluid pressure regulating mechanism 350 comprises a supply valve 355 contained in a chamber 356 and arranged to cooperate with a seat 357 for controlling flow of fluid under pressure from chamber 356 to an outlet chamber 358 provided in bracket 353. A guide member 359 projecting above the seat 357 is provided with a tapered opening for receiving the valve 355 to guide it to its seat and to also cooperate with said valve when in said opening to throttle flow of fluid under pressure from chamber 356 to the outlet chamber 358. The chamber 356 is open directly through pipe 354 and a cut-out valve 360 to the main fluid pressure supply pipe 216 and in operation is therefore adapted to be constantly supplied with fluid under pressure from the latter pipe. The outlet chamber 358 is open to pipe 330 and during running of the generator 1 is adapted to be connected through the shuttle valve device 325 to pipe 327 leading to the direct bounce chambers 19 in said generator.

The supply valve 355 is connected to the end of a stem 361 by a pin 362, said stem projecting from a control piston 363 operatively mounted in a bushing 364 held in position between the casing sections 352 and 354a. An equalizing port 365 through the bushing 364 is provided to permit equalization of fluid pressure from chamber 356 into a chamber 366 at the stem side of the piston 363. At the opposite side of the piston 363 is a control chamber 367 open through a choke 368, a strainer 369 and a passage 369a in the piston stem 361 to chamber 356. A spring follower 356a mounted on the stem 361 in contact with valve 355 is engaged by one end of a precompressed spring 368a the other end of which is supported by the bushing 364, said spring being provided for closing said valve upon substantial equalization of pressure of fluid acting on opposite sides of piston 363.

Disposed in the casing section 354a is a valve seat member 370 held in place by a retainer 371 secured in said casing section. The seat member 370 has a bore open at one end to a passage 372 leading to the outlet chamber 358 and to the control portion 351 of the direct bounce governor device. The opposite end of this bore opens through a valve seat 373 to a chamber 374 which in turn is connected through one or more ports 375 in retainer 371 to the control chamber 367 at the one face of piston 363. Slidably mounted in a bore in the retainer 371 coaxially of the valve seat 373 is a valve 376 arranged to cooperate with seat 373 for closing communication between chamber 374 and passage 372. A plunger 377 slidably mounted in a bore in a partition wall 378 has an extension 379 of smaller diameter than the axial bore in seat member 370 and extending therethrough for contact with the valve 376 for unseating it against a spring 380 carried by said seat member. The plunger 377 is provided on its opposite end with a projection 382 extending into a chamber 381 for cooperation with a valve 383 which is slidably mounted in a bore 384 arranged in coaxial relation to said plunger 377 in an element 385 secured in the casing. The valve 383 may be provided with slots 386 around its edge to provide communication between opposite sides thereof. The chamber 381 is open through a port 387 to passage 372 and thereby to the outlet chamber 358.

A cover 388 is clamped to the end of the casing section 354a opposite that engaging the casing portion 352, and clamped between said cover and the casing section 354a is a flexible diaphragm 389 arranged in coaxial relation with the bore 384 in the element 385. At one side of this diaphragm is a control chamber 390 in which the element 385 is disposed. At the opposite side of the diaphragm is another control chamber 391. The chamber 390 is open through a passage 392 and a pipe 393 directly to one of the direct bounce chambers 19 in the gas generator 1, a chosen restriction to flow of air through this communication being provided as by said pipe being of relatively small flow capacity. The chamber 391 is open through a choke 394 and a passage 395 directly to the fluid pressure supply pipe 354.

A diaphragm follower 396 disposed in chamber 390 engages the adjacent face of diaphragm 389 and has a portion 397 extending through a central opening in said diaphragm and a follower 398 disposed in chamber 391 against the opposite side of the diaphragm, and these followers are rigidly clamped to opposite sides of said diaphragm by a securing element 399 engaging the follower 398 and having internal screw-threaded engagement with the portion 397 of the follower 396.

The diaphragm follower 396 has an integral member 400 disposed in the bore 384 in the element 385, said member 400 having a spherical like surface in sliding contact with the wall of said bore and carrying a sealing ring 401 having sealing contact with said wall. On the innermost end of the integral member 400 is formed a valvet seat 402 arranged for sealing engagement with the valve 383. A shoulder 403 substantially encircling the valve seat 402 and projecting from the wall of bore 384 is provided for contact by valve 386 for unseating said valve from the member 400 upon movement of said member in the direction away from said valve.

The valve seat 402 encircles a fluid pressure release passage 404 extending through the integral member 400 and the follower 396 to a chamber 405 provided at the opposite side of the diaphragm 389 in a coaxially arranged cylindrical portion 406 of the securing element 399. Slidably mounted in the cylindrical portion 406 is one end of a rigid strut 407 the opposite end of which is slidably mounted in a bore in the casing cover 388, which bore is normally in coaxial relation with the cylindrical portion 406. The strut 407 has an axial bore 408 establishing communication between chamber 405 and a passage 409 in the casing cover 388 which passage opens to atmosphere. The opposite end portions of the strut 407 in contact with the wall of the

bore in the casing cover 388 and with the wall of the cylindrical portion 406 are rounded to permit free slight misalignments or wobbling of the diaphragm 389 during movement thereof, which will be later described, and in each end of said strut is a sealing ring 410 having sealing and sliding contact with the respective wall for preventing leakage of fluid under pressure from the control chamber 391 to the atmospheric passage 409.

The diameter of the rigid strut 407 at its point of contact with the cylindrical portion 406 of the securing element 399 is greater than the diameter of the integral member 400 at the opposite side of the diaphragm which is disposed in the bore 384, whereby less area of the diaphragm 389 is subject to pressure of fluid in chamber 391 than is subject to opposing pressure of fluid in chamber 390, in order that a lower pressure of fluid in the latter chamber will provide a force to balance a higher pressure of fluid in the former chamber during operation, to be hereinafter described.

The control portion 351 of the direct bounce cylinder comprises a flexible diaphragm 411 secured around its edge between the casing section 351 and the cover 412. Between the cover 412 and the diaphragm 411 is a control chamber 413 open through a passage 414 and a pipe 415 to the scavenger air receiver 9. At the opposite side of diaphragm 411 is a chamber 416 which is open to atmosphere through a vent port 417.

A follower 418 disposed in chamber 416 against the adjacent face of diaphragm 411 has a stud portion 419 extending centrally through the diaphragm into chamber 413 and over this stud portion in the latter chamber is mounted a follower plate 420 against the diaphragm and a nut 421 having screw-threaded engagement with said stud portion for clamping the central portion of the diaphragm between the follower 418 and plate 420. A regulating spring 422 contained in chamber 416 and supported at one end on the casing section 352 bears against the diaphragm follower 418 urging the diaphragm 411 in the direction of cover 412.

The casing section 352 has a bore arranged in coaxial relation with the diaphragm 411 and containing a plunger 423. The plunger 423 is provided on the end adjacent the diaphragm 411 with a stem 424 extending through a chamber 425 and an axial bore in a bushing 426 secured in the casing section 352, into chamber 416 and thence through said chamber into contact with the diaphragm follower 418. Adjacent to the follower 418 washer 427 is secured to plunger stem 424 by a ring 428 secured to said stem and interposed between one side of this washer and a shoulder in the casing section 352 is a bias spring 429 for maintaining the stem 424 in constant contact with the diaphragm follower 418. The chamber 425, it will be noted, is formed between one end of the plunger 423 and the adjacent end of bushing 426. A sealing ring 430 carried by the bushing 426 has sealing contact with the wall of the casing section 352 in which said bushing is mounted for preventing leakage of fluid under pressure from chamber 425 past said bushing to the atmospheric chamber 416. Another sealing ring 431 carried by bushing 426 has sealing and sliding contact with the stem 424 to prevent leakage of fluid under pressure from chamber 425 along said stem to atmospheric chamber 416.

The plunger 423 has a bore 432 closed at the end adjacent stem 424 and opening at the opposite end to one end of a supply valve chamber 433 the other end of which is closed by plug 434 secured by a ring 435 in the end of said plunger opposite the end from which projects the stem 424. The plug 434 is provided in valve chamber 433 with an annular valve seat 436 arranged for sealing contact by a disc valve 437 contained in said chamber. A spring 438 extending through the bore 432 and chamber 433 acts on the valve 437 for urging it toward seat 436.

The end of the portion of plunger 423 containing the plug 434 is disposed in a chamber 439 and said chamber and chamber 425 at the opposite end of the plunger are both connected to passage 372 from the outlet chamber 358. Midway between its ends the plunger 423 is provided with an annular cavity 440 formed in its outer surface and open by way of a passage 441 to the diaphragm chamber 391 in the fluid pressure regulating mechanism 350. The plunger 423 is further provided with one or more ports 442 opening the annular cavity 440 to bore 432 within said plunger. At either side of cavity 440 the plunger 423 is provided with an annular sealing ring 443 having sealing and sliding contact with the wall of the bore in the casing section in which said plunger is mounted for preventing leakage of fluid under pressure between said cavity and chambers 425 and 439 at opposite ends of the plunger. A similar ring 443*a* carried by the plug 434 and engaging the wall of the bore in plunger 423 in which said plug is disposed is provided to prevent leakage of fluid under pressure from chamber 433 to chamber 439.

The valve seat 436 encircles an axial bore 444*a* extending through the plug 434 and opening to chamber 439, and freely extending through said chamber and bore into contact with the valve 437 is one end of a plunger 444 which is carried by a housing 445 secured to the casing section 352. The plunger 444 comprises an enlarged central portion 446 slidably mounted in a suitable bore in the housing 445. Extending from one end of the central portion 446 through a chamber 447 in said housing and thence through a partition wall 448*a* separating said chamber from chamber 439 is a portion 448 of reduced section from the end of which projects a portion 449 which engages the valve 437, the portion 449 being of smaller diameter than that of bore 444*a* through plug 434 to provide for flow of fluid under pressure through said bore. The chamber 447 is open to atmosphere as by way of a vent port 449. Projecting from the opposite end of the central portion 446 of the plunger is a portion 450 of smaller cross-sectional area than the central portion. The portion 450 is slidably mounted in a suitable bore provided in a plug 451 secured in the housing 445 by a ring 452, and extends beyond the outer end of the plug 451 and of the housing 445. At the inner end of plug 451 is a chamber 453 encircling the portion 450 of plunger 444 and connected by a passage 454 to the annular cavity 440 and thence by way of passage 441 to diaphragm chamber 391 in the fluid pressure regulating mechanism 350.

A sealing ring 455 carried by the plug 451 has sealing contact with the encircling housing 445 for preventing leakage of fluid under pressure from chamber 453 past said plug to atmosphere. Another sealing ring 456 carried by plug 451 has sealing and sliding contact with the portion 450 of the plunger 444 for preventing leakage of fluid under pressure from chamber 453 along said portion of the plunger to atmosphere. A sealing

ring 457 carried by the housing 445 has sealing and sliding contact with the peripheral surface of the central portion 446 of the plunger 444 for preventing leakage of fluid under pressure from chamber 453 to the atmospheric chamber 447, and another sealing ring 458 carried by said housing has sealing and sliding contact with the peripheral surface of the portion 448 of said plunger for preventing leakage of fluid under pressure from chamber 439 to the atmospheric chamber 447.

It will be noted that when fluid under pressure is present in chamber 453 it will act over the area of the central portion 446 of the plunger 444 encircling the portion 450 and produce a force which will urge said plunger in the direction of valve 437. This force however is opposed by pressure of fluid in chamber 439 acting on the exposed end surface of plunger 444 and the differential between these two opposing forces is such as to constantly urge the plunger 444 against the valve 437, but is insufficient to ever unseat the valve 437 against the greater opposing pressure on said valve of spring 438.

When, during operation of the gas generator 1, the piston assemblies tend to move beyond their inner dead points, as determined by the amount of air in the direct bounce chambers 19, in turn governed by the pressure in the scavenger air receiver 9 effective in diaphragm chamber 413 of the control portion 351 of the direct bounce governor 4, as will be later described, the plunger 444 is adapted to be moved into said control portion for momentarily unseating the valve 437, and to accomplish this said plunger may be arranged for control by one or the other of said piston assemblies, in any desirable manner. For the purpose of illustration, however, the end of plunger 450 may be arranged for direct contact by the end of rack 22 secured to and movable with the piston assemblies.

Description of apparatus in addition to that above described

A feed or reducing valve device 459, connected to pipe 125 and therefore adapted to be supplied with fluid under pressure from the feed valve device 124, is provided for maintaining in a pipe 460 fluid at a further reduced pressure, such as one hundred and ten pounds. This pipe 460 leads to a normally closed cut-out valve 461 in turn connected by a pipe 462 to passage 236 in the bracket 34. A hand operated screw 463 is associated with the dump exhaust valve device 40 in coaxial relation with the valve stem 312, for actuating said stem to seat and hold seated the valve 314.

OPERATION OF APPARATUS

Initial conditioning and charging

In operation, let it be assumed that the operator's control lever 137 is initially in "Stop" position. In the drawing the lever 137 is shown in a vertical position merely for the purpose of clarity of illustration. As it is moved from this vertical position to "Stop" position, the position of cam 146 will be changed to permit the stem 105, plunger 104 and follower 151 to be moved sufficiently by spring 133 in the direction of said lever to permit spring 91 acting on the release pilot valve 83 to move said valve and the plunger 77 along with the plunger 104 (the supply valve 113 and supply pilot valve 117 remaining seated under pressure of spring 119) to unseat said release pilot valve, whereby chamber 63 will be opened to atmosphere through port 75 in cylinder 70, port 80 in post 69, port 79 in the plunger 77, thence through the axial bore 78 and port 81 in plunger 77, chamber 82, past said release pilot valve, through port 84, chamber 86, port 87, regulating spring chamber 49 and passage 50.

When chamber 63 is open to atmosphere as just described, chamber 95 at the outer face of the balancing piston 93 will also be open to atmosphere through passages 98, 64 and chamber 63. The reverse bounce chambers 13 in the gas generator 1 will likewise be vented since they are connected to passage 64 by way of pipes 14 and 65. Diaphragm chamber 51 in the operator's control device 3 will also be vented since it is open to the vented pipe 14 through pipe 52 and past the choke 346 in the pick-off valve device 53. With the diaphragm chamber 51 thus open to atmosphere the regulating spring 68 will deflect the diaphragm 48 to a position defined by contact between the follower 54 and the partition wall 60, in which position the release pilot valve 83 will remain open. Also in "Stop" position of the operator's control lever 37, the supply valve 172 in the starting valve portion 47 will be closed while the release valve 182 will be open, opening to atmosphere passage 195 in the bracket.

With passage 195 open to atmosphere, chamber 338 in the shuttle valve device 325 will be vented to permit spring 339 to shift valve 328 into contact with seat 331 whereby the direct bounce chambers 19 in the gas generator 1 will be connected by pipe 327 to pipe 330 leading to the outlet chamber 358 in the direct bounce governor device 4. Chamber 259 in the sequence valve device 37 and chamber 275 in the vent valve device 38 being open to passage 195 will likewise be vented, so that in the latter device the valve 282 will be opened by spring 284 thereby connecting passage 270 in the bracket 34 to atmosphere by way of chamber 278 and a vent passage 464. With passage 270 open to atmosphere the sequence volume 45 and chamber 266 in the sequence valve device 37 will likewise be open to atmosphere permitting the regulating spring 271 therein to move the parts of said device to the position in which they are shown in the drawing, in which position valve 268 is seated on rib 267 and the valve 255 is seated on seat 256 and unseated from seat 258. With the valve 255 unseated from seat 258 the passage 254 in the bracket will be open to the vented passage 195 and thereby chamber 298 in the dump supply valve device 39 will be opened to atmosphere to permit spring 299 to unseat the valve 287. Pipe 231 will also be vented past the check valve 348 to passage 254 and then through the sequence valve device 37 to the vented pipe 195, as well as past the open release valve 182 in the timing valve device 232 associated with the gas generator 1. With passage 270 open to atmosphere through the vent valve device 38, as above described, passage 303 in the bracket 34 will also be open to atmosphere past the check valve 43 and thence through passage 270, whereby chamber 302 in the dump exhaust valve device 40 will be open to atmosphere to permit spring 319 to deflect the diaphragm 301 to the position in which it is shown in the drawing for unseating valve 314. The unseating of valve 314 will connect to the atmospheric passage 316 the passage 289 and thereby pipe 30 connected to piston chambers 28 in the starting valve devices 24 associated with the gas generator. Springs 29 in the starting

valve devices 24 will therefore be maintaining the vent valves 25 closed.

With pipe 231 open to atmosphere as above described, the connected chamber 229 in the direct bounce supply valve device 35 will also be open to atmosphere and permit spring 241 therein to seat the valve 235, and also the valve 226 against the rib 227.

Let it further be assumed that the pressure in the scavenger air receiver 9 is substantially that of atmosphere, as a result of which, a corresponding pressure will be effective through pipe 415 in diaphragm chamber 413 of the control portion 351 of the direct bounce governor device 4 which will permit the regulating spring 422 and the bias spring 429 therein to hold the parts of the control portion 351 in the position in which they are shown in the drawing.

Now let it be assumed that pipe 216 is connected to a source of fluid at a desired pressure, such as one thousand pounds. Fluid thus supplied to pipe 216 will flow to the feed valve device 124 and also through the normally open cut-out valve 360 and pipe 354 to the direct bounce governor device 4. The feed valve device 124 will then operate to provide in pipe 125 fluid at the desired reduced pressure, such as three hundred pounds, which will flow through said pipe to passage 126 in the pipe bracket 34 and also to the feed valve device 459. Fluid thus supplied to passage 126 in the bracket 34 will flow to the annular cavity 127 encircling the bushing 101 in the operator's control device and thence through port 128 therein to chamber 129 encircling the plunger 104 and thence through ports 129a in said plunger to the supply valve chamber 111. Fluid supplied to passage 126 in the bracket 34 will also flow to the supply valve chamber 236 in the direct bounce supply valve device 35, the supply valve 235 being seated at this time. The cut-out valve device 461 being normally closed, the feed valve device 459 will merely operate to charge pipe 460 from pipe 125 to a pressure, such as one hundred ten pounds, determined by the adjustment of said feed valve device.

When fluid under pressure is supplied through pipes 216 and 354 to the direct bounce governor device 4, as above mentioned, it will flow into the supply valve chamber 356 therein and also through passage 395 and choke 394 into diaphragm chamber 391 and from the latter chamber through passage 441 and ports 442 in the plunger 423 to the valve chamber 433 in said plunger.

Now assuming that the piston assemblies of the gas generator are initially in some position other than their innermost positions, the valve 437 will be seated with diaphragm 411 and plunger 423 in the position in which they are shown in the drawing and which position will be assumed when the pressure in diaphragm chamber 413 and in the scavenger receiver 9 is substantially that of atmosphere, as before mentioned. As a result, pressure in diaphragm chamber 391 of the fluid pressure regulating mechanism 350 will gradually increase through choke 394 and provide a force on diaphragm 389 which will move same in the direction of chamber 390 for thereby actuating the integral member 400 into seating engagement with the valve 383 and for then shifting said valve against plunger 377 to unseat the valve 376. Upon unseating of valve 376 the chamber 367 at one side of the control piston 363 will be opened past said valve to passage 372 and thence to the outlet chamber 358 which at this time is open through the shuttle valve device 325 to pipe 327 leading to the direct bounce chambers 19. The pressure in the supply piston chamber 367 will thereby be reduced sufficiently below the supply pressure in chamber 366 to provide a force on the piston 363 to move same in a direction to pull the supply valve 355 away from the seat 357, whereupon fluid under pressure from the supply valve chamber 356 will flow to the outlet chamber 358 and thence through pipe 330, the shuttle valve device 325 and pipe 327 to the direct bounce chambers 19, by way of chambers 32 and ports 31 in the gas generator 1. As pressure of fluid in the direct bounce chambers 19 is thus increased, such pressure acting on the direct bounce pistons 18, 18a will move said pistons in the direction of their innermost dead points, since the reverse bounce chambers 13 are, at this time, open to atmosphere through the operator's control valve device 3 in "Stop" position, as above described.

As fluid under pressure is thus supplied to the direct bounce chambers 19 it will equalize through pipe 393 back into diaphragm chamber 390 in the direct bounce governor device 4 and thereby provide a force on diaphragm 389 proportional to the increase in pressure in the direct bounce chambers 19 and opposing pressure of fluid in chamber 391. As the piston assemblies of the gas generator 1 are moved into their innermost dead positions, the rack 22 associated with the air compressor piston 12a will operate plunger 444 to unseat the valve 437 and thereby establish a communication between diaphragm chamber 391 and passage 372 which is open to the outlet chamber 358 and thereby to the direct bounce chambers 19. The venting capacity of valve 437, when opened by rack 22 as just described, so exceeds the flow capacity of choke 394 to supply fluid to diaphragm chamber 391, that the pressure in said chamber will then promptly reduce into the direct bounce chambers 19 to a sufficiently low degree to permit pressure of fluid in the direct bounce chambers 19 and diaphragm chamber 390 plus pressure of spring 380 to deflect the diaphragm 389 against the reduced pressure of fluid in chamber 391 to permit closing of valve 376 by said spring.

When the valve 376 in the direct bounce governor device 4 is closed as just described, fluid at the supply pressure in chambers 366, 356 at one side of piston 363 will promptly equalize through the passage 369a and choke 368 into piston chamber 367 whereupon spring 368a will actuate said piston to close the valve 355 for preventing further flow of fluid under pressure to the outlet chamber 358 and thereby to the direct bounce chambers 19 in the gas generator 1. With valve 437 still open the pressure of fluid in diaphragm chamber 390 will then substantially equalize with that in chamber 391 and since a greater area of diaphragm 389 is exposed to pressure of fluid in chamber 390 than is exposed in chamber 391, a force will be provided on said diaphragm which will actuate same to move member 400 out of engagement with valve 383 to thereby open chamber 381 to atmosphere through passage 404 in the diaphragm follower 396 and thence through bore 408 in the rigid strut member 407. When chamber 381 is thus opened to atmosphere the fluid under pressure flowing to passage 372 past the open valve 437 in the control portion 351 will be vented to atmosphere, and along with it the fluid under pressure from the direct bounce chambers 19. As the fluid under pressure is thus released from the direct bounce chambers 19 the pressure in diaphragm

chamber 390 will correspondingly reduce, but under the condition being described the venting capacity of the open valve 437 is so in excess of the flow capacity of choke 394 to supply fluid to diaphragm chamber 391 that the pressure in said chamber 391 will be reduced substantially with the reduction in pressure in chamber 390 and in the direct bounce chambers 19, so that upon complete release of fluid under pressure from the direct bounce chambers 19 and from the connected chamber 390 at the opposite side of diaphragm 389, the pressure in diaphragm chamber 391 will be substantially that of the atmosphere so that said diaphragm will remain in the position in which the valve 383 is open.

If, at the time fluid under pressure is initially supplied to the direct bounce governor device 4, as just described, the piston assemblies of the generator happen to be in their innermost positions opening the valve 437 in the control portion 351 of the direct bounce governor device 4, the fluid under pressure supplied through choke 394 into diaphragm chamber 391 will merely equalize past valve 437 into passage 372 and be dissipated to atmosphere past the valve 383, if open. In case the valve 383 is closed at this time, the fluid flowing to passage 372 will equalize through the outlet chamber 358 into the direct bounce chambers 19 of the generator and from thence through pipe 393 into diaphragm chamber 390 and will build up therein substantially with the increase in pressure of fluid in chamber 391. When a sufficient increase in pressure is thus obtained in chamber 390 to overcome the pressure in chamber 391 acting on the smaller exposed area of diaphragm 389, said diaphragm will operate to open the valve 383 and dissipate the pressure from both of said chambers, as well as from the direct bounce chambers 19 in the generator, and said diaphragm will then remain in the position in which valve 383 is open.

It will now be briefly noted that when the control lever 137 is moved to "Stop" position, and fluid from the supply pipe 216 will be connected to the direct bounce governor device 4, the piston assemblies of the gas generator 1 will move to their innermost dead points, if not already so positioned, under pressure of fluid supplied to the direct bounce chambers 19 by operation of said governor device, following which said governor device will operate to open said chambers to atmosphere for releasing fluid under pressure therefrom without any change in position of said piston assemblies occurring.

In the above description it was assumed that the scavenger air receiver 9 and hence the diaphragm chamber 413 in the control portion 351 of the direct bounce governor device 4 were at atmospheric pressure under which condition the inner dead points or positions of the piston assemblies would be the most inward positions which said assemblies could ever assume. It is desired to point out, however, that the inner dead points of the piston assemblies at which the valve 437 is opened to cause venting of fluid under pressure from the direct bounce chambers 19 of the generator and from chamber 390 in the direct bounce governor device 4, as above described, will vary in accordance with the pressure of fluid in the scavenger receiver 9 and hence in accordance with that in diaphragm chamber 413 and the position of diaphragm 411 and of the valve seat 436 in plunger 423. Therefore if the scavenger receiver 9 is charged with fluid under pressure when the operator's control lever 137 is moved to the "Stop" position the valve 437 will be opened at the inner dead points of the piston assemblies as determined by the pressure of fluid in the scavenger receiver 9, but in the initial charging of the apparatus, as above considered, diaphragm 389 in the governor device 4 will move to and then remain in the position for venting the direct bounce chambers 19, in the same manner as above described.

Normal starting of gas generator 1

When the temperature of the gas generator 1 is such that the piston assemblies therein will move without undue sluggishness, due for instance to congealed lubrication, said generator may be started as follows.

The operator's control lever 137 will be moved from "Stop" position through the slot 210 in the ledge 209 and thence to the "Start" position at the opposite end of the short portion 208 of the slot 206. This movement of the operator's control lever 137 will actuate the cam 146 and follower 151 to displace, as a unit, the plunger 104, the seated supply valve 113, the seated supply pilot valve 117, the pin 120 and the plunger 77 against the release pilot valve 83 and move said release pilot valve against spring 91 until it becomes seated. When the release pilot valve 83 becomes seated as just described it will hold the plunger 77 and thereby the pin 120 against further movement whereupon continued movement of the plunger 104 in the direction of these parts will cause said pin to first unseat the supply pilot valve 117 and then the supply valve 113, whereupon fluid under pressure from the supply valve chamber 111 will flow past said supply valves to chamber 63 and thence through passage 64 and pipes 65 and 14 to the reverse bounce chambers 13 in the gas generator 1. Fluid from chamber 63 will also flow by way of passages 64 and 98 to the balancing piston chamber 95 to act on the piston 93 to counterbalance the same pressure acting in chamber 63 on the cylinder 70.

As fluid under pressure is supplied to the reverse bounce chambers 13, as just described, fluid at the same pressure will also flow through the pick-off valve device 53, by way of the check valve 344 therein, and thence through pipe 52 to diaphragm chamber 51 in the operator's control device 3. As the pressure of fluid in chamber 51 then increases it will deflect diaphragm 48 against the regulating spring 68. With the operator's control lever 137 in the "Start" position displacement of the plunger 104 will be limited, so that deflection of diaphragm 48 against the regulating spring 68 will be relative to said plunger. The seated release pilot valve 83 and plunger 77 and thereby pin 120 will move with the diaphragm 48 due to the pressure of spring 119 thereon and thus permit movement of the supply valve 113 and supply pilot valve 117 in the direction of the seat for said supply valve also under the action of said spring. When sufficient pressure is thus obtained in diaphragm chamber 51, corresponding to the position of the operator's control lever 137 in "Start" position, the diaphragm 48 will assume a position in which both the supply valve 113 and supply pilot valve 117 will be seated to thereby prevent further flow of fluid under pressure to chamber 63 in the operator's control device and to the reverse bounce chambers 13 in the gas generator 1. It will thus be seen that when the operator's control lever 137 is moved to "Start" position the reverse bounce chambers 13 in the gas generator 1 will become charged with

fluid at a pressure, such as twenty pounds, corresponding to the position of said lever. In the gas generator 1 this pressure in the reverse bounce chambers 13 will move the piston assemblies apart to their outermost positions in which the direct bounce pistons 18, 18a will be disposed in contact with the end walls of the safety spaces 33 at the outer end of the direct bounce chambers 19. The direct bounce chambers 19, 32 will at this time be open to atmosphere through the direct bounce governor device 4, as described under "Initial Conditioning and Charging."

The movement of the operator's control lever 137 into the short portion 208 of the slot 206 and thence to "Start" position therein will also cause closing of the release valve 182 and opening of the supply valve 172 in the starting valve portion 47 of the operator's control device. Thereupon fluid under pressure supplied by the feed valve device 124 through pipe 125 and passages 126 and 170 to the supply valve chamber 168 in the starting valve portion 47 will flow past the supply valve 172 to the release valve chamber 175 and thence to passage 195 in the bracket 34, it being noted that this supply of fluid to passage 195 will occur at the same time as fluid under pressure is being supplied to the reverse bounce piston chambers 13 in the gas generator 1.

Fluid under pressure thus supplied to passage 195 will flow to piston chamber 338 in the shuttle valve device 325 and therein act on piston 337 to move it against spring 339 to unseat the valve 328 from its seat 331 and to move it into engagement with its opposite seat 329 so as to disconnect pipe 327, leading to the direct bounce chambers 19 in the gas generator 1, from pipe 330 connected to the direct bounce governor device 4 and to open said pipe 327 to passage 303 in the bracket 34.

Fluid under pressure supplied to passage 195 will also flow to chamber 275 in the vent valve device 38 to act on piston 272 to urge it against spring 284 for permitting closing of valve 282 by spring 283. Fluid from passage 195 will also flow to chamber 259 in the sequence valve device 37. As before described the valve 255 in the sequence valve device will at this time be seated on its lower seat 256, so that fluid supplied to chamber 259 will be able to flow past said valve to chamber 253 and thence into passage 254. Fluid thus supplied to passage 254 will flow to piston chamber 298 in the dump supply valve device 39 and therein act on piston 297 to move it against spring 299 for seating the valve 287 against seat 288 for thereby closing communication between passage 286 and passage 289.

When the direct bounce pistons 18, 18a in the gas generator 1 are moved into the safety spaces 33 by pressure of fluid provided in the reverse bounce chambers 13, as above described, the timing valve device 232 will be operated thereby, as through the medium of lug 234 on rack 22, to establish communication between pipe 233, connected to pipe 14 connecting together the reverse bounce chambers 13, and pipe 231, whereupon fluid under pressure supplied by the operator's control device in "Start" position to pipe 14 will also flow to pipe 231 and thence to chamber 229 in the direct bounce supply valve device 35. When sufficient pressure is thus obtained in chamber 229 to overcome the opposing pressure of spring 241 said pressure will unseat the valve 226 from the seat rib 227, whereupon fluid pressure from pipe 231 will also become effective in chamber 228 thereby exposing the full effective area of diaphragm 219 to pressure of fluid from said pipe. The increased fluid force thereby provided on diaphragm 219 will promptly overcome that of spring 241 and move said diaphragm against said spring to actuate stem 238 to unseat the supply valve 235. Fluid under pressure supplied to passage 126 by the feed valve device 124 will then flow to passage 237 through which it is supplied to the feed valve device 36. The feed valve device 36 will then operate to reduce this pressure to a desired degree, such as one hundred and fifty pounds, and supply fluid at such reduced pressure to passage 245.

Fluid under pressure thus supplied to passage 245 in the bracket 34 will unseat check valve 42 against the spring 342 and flow to passage 286 and thence into valve chamber 285 of the dump supply valve device 39, until such pressure in said chamber is increased to a chosen degree, corresponding to the force of said spring on said check valve 42, at which time said spring will close said check valve. It will be noted that the valve 287 in the dump supply valve device 39 is, at this time, closed by fluid under pressure supplied from passage 195 through the sequence valve device 37 to passage 254, as before described.

At the same time, fluid from passage 245 will also flow through the adjustable choke 44 to passage 340 and thence past the check valve 41 to passage 303, from which it will flow in one direction through the shuttle valve device 325 to pipe 327 and thence to the direct bounce chambers 32 and safety spaces 33 in the gas generator 1. Fluid supplied to passage 303 will also flow in the opposite direction to chamber 302 in the dump exhaust valve device 40 and therein act on diaphragm 301 to move it against spring 319 into contact with stop 317, and during such movement actuate the bias spring 321 to seat the valve 314 for closing communication between passages 289 and 316. Fluid from passage 303 will also flow past check valve 43 to passage 270 and thence to the timing volume 45 and to the closed valve chamber 280 in the vent valve device 38 and to chamber 266 in the sequence valve device 37.

After a desired pressure of fluid is thus obtained in chambers 32 and the cushion spaces 33 in the gas generator 1 and in the sequence volume 45 as above described, said pressure acting in chamber 266 in the sequence valve device 37 will overcome the opposing force of spring 271 and urge the valve 268 out of contact with the seat rib 267. As soon as the valve 268 is thus opened fluid will promptly flow from chamber 266 into chamber 269 and become effective over the whole lower area of diaphragm 246 for creating a force to so overbalance the opposing force of spring 271 as to snap the diaphragm 246 in an upwardly direction for moving the valve 255 out of engagement with seat 256 and into contact with seat 258. This operation of valve 255 will cut off further flow of fluid under pressure to passage 254 leading to piston chamber 298 in the dump supply valve device 39 and open said chamber to the atmospheric passage 257, whereupon the pressure of fluid in said chamber will be promptly released to atmosphere. Spring 299 will then move the piston 297 to the position in which it is shown in the drawing for unseating the valve 287, whereupon fluid under pressure in passage 286 will flow to passage 289 and thence through pipes 290 and 30 to piston chambers 28 in the starting valve devices 24.

The pressure of fluid thus provided in piston

chamber 28 of each starting valve device 24 will overcome the opposing force of spring 29 on the piston 27 and actuate said piston to open the vent valve 25. Upon opening of the vent valve 25 in the starting valve devices fluid under pressure will be released from the reverse bounce chambers 13 at such a rate, exceeding that of the supply by operation of the operator's control valve device in "Start" position, as to effect a reduction in pressure in said chambers sufficient for the fluid under pressure in chambers 32 and cushion spaces 33, acting on the direct bounce pistons 18, 18a, to move the piston assemblies in the direction of each other so as to compress the air therebetween, after closing of the inlet and exhaust ports 7 and 8, to a sufficient degree to cause compression ignition upon injecting fuel into the power cylinder 6.

It will be noted that the supply of fluid under pressure to chambers 32 and to the safety spaces 33 in the gas generator 1 and to the sequence volume 45 as above described is regulated or delayed by choke 44 to insure, before operation of the sequence valve device 37 to effect operation of the dump supply valve device 39 and in turn the starting valve devices 24, that the chambers 32 in the gas generator will be fully charged to a desired pressure, and that passage 286 will likewise be fully charged, it being desired to point out that in practice the passage 286 constitutes a volume which when fully charged provides the fluid under pressure for actuating the starting valve devices 24, as above described.

When the sequence valve device 37 operates to open passage 254 to the atmospheric passage 257 for effecting opening of the dump supply valve 287 as above described, fluid under pressure will also be released from pipe 231 past the check valve 348 to the vented passage 254, but with the reverse bounce pistons 18, 18a still in the safety spaces 33 fluid under pressure will be supplied to pipe 231 through the timing valve device 232. However, as the piston assemblies move out of the safety spaces 33 by the expansion of compressed fluid in chambers 32 as above described, the lug 234 will move away from plunger 181 in the timing valve device 232 to permit closing of the supply valve 172 therein by spring 177 and opening of the release valve 182 by spring 189, whereupon the pressure of fluid in pipe 231 and thereby in chambers 228 and 229 in the direct bounce supply valve device 35 will be promptly reduced to that of atmosphere by way of the timing valve device 232, and also past check valve 348 and the open valve 255 in the sequence valve device 37.

It is desired to point out that the check valve 348 is not necessary if proper venting of fluid under pressure from pipe 231 can be assured by operation of the timing valve device 232 in response to movement of the direct bounce pistons 18, 18a out of the safety spaces 33, otherwise the check valve 348 is necessary, in which case the release valve 182 and its function in the timing valve device 232 could be dispensed with, if desired, although it is not necessary.

When the fluid under pressure is vented from chambers 229, 228 in the direct bounce supply valve 35 by way of either or both the check valve 348 and the timing valve 232, as above described, the spring 241 will then close the supply valve 235 to prevent further flow of fluid under pressure from passage 126 to passage 237 leading to the feed valve device 36 for thereby cutting off further supply of fluid under pressure from said feed valve device to passage 245 and thence through choke 44 and past check valve 41 to passage 303 and through the shuttle valve device 325 to the direct bounce chambers 32, 19. It will be noted that this supply of fluid to the direct bounce chambers 32, 19 will be cut off promptly upon venting of fluid under pressure from pipe 231 by operation of the sequence valve device 37 or by operation of the timing valve device 232 upon movement of the direct bounce piston 18, 18a out of the safety spaces 33, so that continued movement of the piston assemblies by expansion of the fluid under pressure in the direct bounce chambers 19 will permit the pressure in these chambers to reduce. This reduction in pressure in the direct bounce chambers is effective through pipe 327, the shuttle valve device 325 and passage 303 in chamber 302 of the dump exhaust valve device 40 and the spring 319 in the dump exhaust valve device is so adjusted that at substantially the time the air compressing pistons 12, 12a are at the center of their stroke the direct bounce chamber pressure will be so reduced that said spring will deflect diaphragm 301 in an upwardly direction into contact with button 313 on the valve stem 312 and actuate said button to crack open the valve 314. Immediately upon cracking open of valve 314 pressure of fluid in chamber 310 will start flowing past said valve to passage 316 and thereby reduce the differential in opposing forces on said valve. The pressure in chamber 310 at the same time, however, acts upwardly on plunger 311 and the difference between the upward force on said plunger and the differential in forces over the valve 314 will promptly increase to a degree sufficient to overcome the opposing force of bias spring 321 and snap said valve relative to the diaphragm 301 to a wide open position for rapidly releasing fluid under pressure from said passage 289, pipe 290 and thereby from piston chambers 28 in the starting valve devices 24 to atmosphere by way of passage 316. Springs 29 in the starting valve devices 24 will thus close the vent valves 25 whereupon during further movement of the piston 12, 12a to their inner dead points, the fluid remaining in the reverse bounce chambers 13 will be compressed to a degree substantially equal to that being provided to said chambers by the operator's control valve device 3 in "Start" position.

It will thus be seen that upon the initial stroke of the piston assemblies in the direction of their inner dead points the amount of air in the direct bounce chambers 19 will be limited by promptly cutting off of the supply by operation of the direct bounce supply valve device 35, while the vent valves 25 will be closed to insure a chosen pressure in the reverse bounce chambers 13 at the end of the inward travel of said assemblies.

At the time of starting and during the warming up period of the generator 1 the delivery pipe 10 will usually be open to atmosphere and the amount of air bottled in the direct bounce chambers 19 and provided in the reverse bounce chambers 13, with the operator's control device in "Start" position, will provide the energy required for coaction, respectively, with that of the compressed air in the clearance space of the air compressor pistons 18, 18a at the end of their air compressing stroke, and the power developed in the power chamber 6, to maintain oscillation or prevent stalling of the piston assemblies.

During this reciprocation of the piston assemblies the pressure in the reverse bounce chambers 13 will increase to a maximum degree at the

inner dead points of said assemblies and reduce to a minimum degree at the outer dead points, and these fluctuations in pressure will be effective through pipes 14 and 65 and passages 64 and 98 in, respectively, chambers 63 and 95 of the operator's control device 3, but will have no effect upon operation of said contol device for reasons before described. However, the pressure in the diaphragm chamber 51 of the operator's control device, which is also connected to the reverse bounce chambers 13 in the generator 1 through the pick-off valve device 53, will remain substantially constant and at a pressure slightly less than the maximum degree obtained in the reverse bounce chambers 13, by way of the check valve 344 which permits flow of fluid from said chambers to said pipe, the choke 346 being of such size as to permit only slight flow of fluid pressure from said pipe back to said chambers during reciprocation of the piston assemblies in the generator. Thus with the operator's control lever 137 in the "Start" position the pressure of fluid obtaintd in pipe 52 will correspond substantially to said position so that said device may maintain a substantially constant amount of air in the reverse bounce chambers 13 determined by said position.

The only purpose of choke 346 in the pick-off valve device 53 is to permit pressure of fluid in pipe 52 to reduce by flow back to pipe 14 in response to a change in position of the operator's control lever 137 which would reduce the quantity of air in the reverse bounce chambers 13, as will be later described. The choke 347 in the pick-off valve device 53 connecting pipe 52 to atmosphere provides a constant restricted flow of fluid under pressure from pipe 52 for blowing from said pipe dirt or foreign matters which otherwise might reach and clog the choke 346. It is desired to point out that, if desired, the choke 347 could also embody the function of choke 346 and the latter choke could then be omitted.

In case there should be leakage of fluid under pressure to the reverse bounce chambers 13, for instance past the supply valve 113 or the supply pilot valve 117 in the operator's control device, or in case of leakage of gas from power chamber 6 past the power piston 5 or 5a to said chambers, such leakage would tend to increase the maximum pressure of fluid therein and thereby in the pipe 52. In case the pressure of fluid in pipe 52 should thus tend to increase a corresponding increase will occur in diaphragm chamber 51 in the operator's control device 3 and move said diaphragm against the regulating spring 68 relative to the plunger 77 and thus permit unseating of the release pilot valve 83 by spring 91 to dissipate the excess fluid from the reverse bounce chambers 13. In case the leakage is continuous the diaphragm 51 may move against spring 68 to permit opening of the release valve 83 only an amount sufficient to offset such leakage or, in other words, the release pilot valve 83 may be held open just sufficient to permit dissipation of fluid from the reverse bounce chambers 13 at a rate corresponding to the leakage into said chambers.

In case however, the amount of air in the reverse bounce chambers should become reduced to a degree below that corresponding to the position of the operator's control lever 137, a corresponding reduction in pressure in diaphragm chamber 51 of the operator's control device will occur which will permit the regulating spring 68 to deflect diaphragm 48 in a direction to unseat the supply pilot valve 117, and the supply valve 113 if necessary, in order to supply fluid to the reverse bounce chambers 13 to compensate for such leakage. When the amount of air in the reverse bounce chambers is then restored to that corresponding to the position of the operator's control lever 137, the consequent increase in pressure in pipe 52 on diaphragm 48 will deflect said diaphragm against the regulating spring 68 to permit closing of the supply pilot valve 117, or if the leakage is continuous, the supply pilot valve 117 may be maintained open a degree sufficient to supply fluid to the reverse bounce chambers in an amount to just offset such leakage.

It will thus be seen that, while during operation of the generator 1 the pressure of air in the reverse bounce chambers 13 will vary from a maximum pressure to a minimum pressure, a substantially constant pressure somewhat less than said maximum will be maintained in pipe 52 to control diaphragm 48 in the operator's control device, whereby the amount or quantity of air in said chamber will be maintained substantially constant and corresponding to the adjusted position of the operator's control lever 137.

When charging the chambers 32 and safety spaces 33 in the generator in preparing to start said generator, as above described, the diaphragm chamber 390 in the direct bounce governor device 4 will be charged with the same pressure, and with the chamber 391 vented past the open valve 437, the diaphragm 389 will be maintained in the position for opening valve 383 so as to release fluid under pressure vented from chamber 391 past the open valve 437, as above described. After the piston assemblies have been started and are reciprocating the pressure in diaphragm chamber 390 will reduce but, due to the restriction to flow of fluid under pressure through the relatively small pipe 393, the reduction will be limited to substantially a chosen mean of the fluctuating pressure in the direct bounce chambers 19.

On the initial power stroke of the piston assemblies, the valve 437 in the direct bounce governor device 4 will close as the piston assemblies move out of their innermost position, but on each succeeding stroke of said piston assemblies to their innermost positions the plunger 444 will be actuated by rack 22 to momentarily poke open the valve 437, as a result of which, the continuous supply of fluid under pressure to chamber 391 through choke 394 will build up a pressure therein proportional to the degree or time of opening of valve 437, and this pressure will just balance the opposing force developed by the mean direct bounce chamber pressure effective in chamber 390, if there is no leakage of fluid under pressure from the direct bounce chambers 19, and in which case the diaphragm 389 will remain in the position in which valve 383 is open. However, if there should be leakage from the direct bounce chambers 19, then upon a sufficient reduction in pressure in diaphragm chamber 390, the pressure of fluid obtained in chamber 391 will actuate diaphragm 389 to seat the valve 383 and open valve 376. Upon this opening of valve 376 fluid under pressure will be vented from the supply piston chamber 367 past said valve to passage 372 and thence to the outlet chamber 358 and pipe 330 whereupon pressure of fluid in chamber 356 will actuate piston 363 to open the supply valve 355 to permit flow of fluid under pressure from chamber 356 to the outlet chamber 358 and pipe 330, which

at this time is disconnected from the direct bounce chambers 19 by the shuttle valve 328 being seated on seat 329. As fluid under pressure is thus supplied to the outlet chamber 358 it will also flow into piston chamber 367 through choke 368 in piston 363 as well as by way of passage 372 and past the open valve 376, and when the pressure of fluid in said piston chamber thus becomes increased to a sufficient degree the spring 368a will actuate piston 363 to close the valve 355, following which, equalization of pressures in the supply chamber 356 and outlet chamber 358 and pipe 330 will occur through the choke 368 in said piston and past the open valve 376 which will remain open, due to the fact, that when the pressure in the outlet chamber 358 builds up, as above described, to a degree exceeding that in diaphragm chamber 391, there will be no flow of fluid under pressure away from chamber 391 upon unseating of valve 437, and pressure of fluid in chamber 391 will then also increase to that of the supply fluid from pipe 354. This high pressure in chamber 391 will then maintain the diaphragm 389 deflected to the position for holding valve 376 open against the mean direct bounce chamber pressure effective in chamber 391. The fact that the outlet chamber 358 and pipe 330 will become charged to supply pressure in pipes 354 and 216 during starting of the generator, in case of leakage of fluid under pressure from the direct bounce chambers 19, and when said chambers 19 are disconnected from pipe 330, is however immaterial.

Running of the generator 1 after starting

After the generator has been started and is running, the operator will move lever 137 from the "Start" position through the slot 212 in ledge 209 to the "Normal Running Reverse Bounce Pressure" position in the long portion 207 of the slot 206 and while this operation will have no effect upon the reverse bounce governor portion 46 of said device, and thereby on the quantity of air in the reverse bounce chambers 13, it will permit operation of the starting valve portion 47 of said device to close communication between the fluid pressure supply passage 170 and passage 195 and will open the latter passage to atmosphere.

Upon opening passage 195 in the bracket 34 to atmosphere fluid under pressure will be released from chamber 338 in the shuttle valve device 325 and spring 339 therein will then actuate the piston 337 to move the valve 328 out of engagement with seat 329 and into contact with seat 331. Pipe 327 from the direct bounce chambers 19 will thereby be disconnected from passage 303 in the bracket and connected to pipe 330 leading to the direct bounce governor device 4. As fluid under pressure is vented from the passage 195 it will also be released from chamber 275 in the vent valve device 38 to render spring 284 therein effective to open the check valve 282, whereupon fluid under pressure will be released from the sequence volume 45 and from chambers 266 and 269 in the sequence valve device 37 to permit spring 271 to return the valve 255 to its lower position. At the same time, fluid under pressure will be released from passage 303 and thereby from chambers 302 in the dump exhaust valve device 40 past the check valve 43 and thence by way of passage 270, whereby the parts of said valve device will be moved by spring 319 to the position in which they are shown in the drawing in order to maintain chambers 28 in the starting valve devices 24 at the gas generator open to atmosphere so as to ensure that the vent valves 25 will remain closed during subsequent running of said generator.

When the shuttle valve device 325 operates as just described to connect the pipe 327 from the direct bounce chambers 19 to pipe 330 leading to the direct bounce governor device 4, if there is no pressure in the outlet chamber 358 and pipe 330 a slight reduction in pressure in the direct bounce chambers 19 will occur due to equalization into chamber 358 and pipe 330, and the mean direct bounce chamber pressure in diaphragm chamber 390 will correspondingly reduce. Under this condition the pressure of fluid in diaphragm chamber 391 will deflect the diaphragm 389 in the direction of chamber 390 to seat valve 383 and then unseat valve 376 to cause operation of piston 366 to open the supply valve 355, whereupon fluid under pressure from the supply valve chamber 356 will flow to the outlet chamber 358 and thence through pipe 330, the shuttle valve device 325 and pipe 327 to the direct bounce chambers 19. As the amount of fluid under pressure in the direct bounce chambers 19 then increases the mean pressure of such fluid will become effective in chamber 390, and when this latter pressure is increased sufficiently to deflect diaphragm 389 against the pressure of fluid in chamber 391 the valve 376 will be seated by spring 380. Upon closing of valve 376 pressure of fluid in the supply valve chamber 356 will equalize through choke 368 into the piston chamber 367 and when the differential in opposing pressures of fluid on said piston is sufficiently reduced spring 368a will seat supply valve 355 and prevent further flow of fluid under pressure to the outlet chamber 358 and thence to the direct bounce chambers 19.

If the outlet chamber 358 and pipe 330 are charged with fluid at supply pressure at the time the shuttle valve device 325 operates to connect said pipe to pipe 327 and thence to the direct bounce chambers 19, as above described, the high pressure of fluid in chamber 358 and pipe 330 will suddenly equalize into the direct bounce chambers 19. The volume of the outlet chamber 358 and the pipe 330 is relatively small, however, so that equalization of fluid under pressure therefrom into the direct bounce chambers 19 will not materially increase the amount of fluid therein, but if the increase is sufficient to cause a sufficient increase in the mean pressure effective in chamber 390 on the diaphragm 89 to overcome the opposing force of pressure of fluid in chamber 391, said diaphragm will be deflected in the direction of chamber 391 to unseat the valve 383 for releasing fluid under pressure from the direct bounce chambers 19 by way of the outlet chamber 358, passage 372 and thence past said valve until the amount of fluid in the direct bounce chambers 19 and the mean pressure thereof in diaphragm chamber 390 is reduced sufficiently to permit pressure of fluid in chamber 391 to actuate diaphragm 389 to seat valve 383.

From the above description it will now be seen that when, in response to movement of the operator's control lever 137 out of "Start" position to the "Normal Running Reverse Bounce Pressure" position and the consequent connecting of the direct bounce chambers 19 to the direct bounce governor device 4, the pressure of fluid in said chambers will be promptly adjusted in accordance with that effective in the diaphragm chamber 391 of the direct bounce governor device 4. It will further be noted that the pressure of fluid in chamber 391 will be adjusted in accordance

with the degree and length of time of opening of the valve 437 by the rack 22 in turn governed by the position of diaphragm 411 and the inner dead points of the piston assemblies. With the scavenger receiver 9 at atmospheric pressure the diaphragm 411 and, normally, the plunger 444 in the control portion 351 of the direct bounce governor device 4 will be in the extreme left-hand position, as viewed in Fig. 8 of the drawing, and the inner dead points of the piston assemblies will be the innermost positions which they will ever assume, so that the extent and time of opening of the valve 437 will be less than if said diaphragm and plunger were in a position to the right of that shown and the inward stroke of the piston assemblies were less, as will be considered in detail later.

In starting the generator and during the warming-up period therefore the delivery pipe 10 will usually be open directly to atmosphere as before mentioned so that the pressure of fluid in the scavenger receiver 9 will remain substantially at atmospheric pressure, and during this period the direct bounce governor device 4 will operate, as above described, to maintain in the direct bounce chambers 19 a sufficient amount of air to provide the energy required for moving the piston assemblies to their innermost dead points. However, when the atmospheric connection to delivery pipe 10 is closed and motive gas is supplied from the generator 1 to operate the turbine, the operation of the generator will build up a pressure in the scavenger receiver 9, and as this pressure increases a corresponding increase will occur through pipe 415 in diaphragm chamber 413 of the direct bounce governor device 4 to deflect the diaphragm 411 therein against the spring 422 to a corresponding position.

It will be noted that as the pressure in the scavenger receiver 9 increases, a corresponding increase will occur in the amount and therefore energy of the compressed air retained in the clearance space in the air compressing chambers 15 at the end of the outward stroke of the piston assemblies and that this energy will coact with that of the air in the direct bounce chambers 19 to move the piston assemblies inwardly of the generator. Also the pressure of the fresh air charge in the power chamber 6 will increase with the pressure in the scavenger receiver 9 which together with the energy of air in the reverse bounce chambers 13 will oppose such inward movement. It is desirable that the amount and therefore energy of air in the direct bounce chambers 19 be so varied with respect to the coacting and opposing forces or energies just mentioned, that the inward stroke of the piston assemblies will reduce or increase in substantial proportion, respectively, to the increase or reduction in pressure in the scavenger receiver 9, and to at the same time maintain a substantially constant final compression pressure in the power chamber 6, regardless of the pressure in the scavenger receiver 9 and hence the pressure of the fresh air charge to said chamber from said receiver. The direct bounce governor device 4 will automatically accomplish this end as will now be described.

In the direct bounce governor device 4, diaphragm 411 and the connected seat for valve 437 will move inward against spring 422 in proportion to the increase in pressure in the scavenger receiver 9 which will lengthen the time said valve is open for each inward stroke of the piston assemblies, for in turn correspondingly reducing the pressure in diaphragm chamber 391 to permit the mean direct bounce chamber pressure in chamber 390 to deflect diaphragm 389 in the direction of chamber 391 for opening valve 383 for releasing air from the direct bounce chambers 19. As air is thus released from the direct bounce chambers 19 the energy of the air remaining in said chambers at the end of the outward stroke of the piston assemblies will be reduced with respect to the opposing and coacting forces above mentioned so as to shorten the inward stroke of the piston assemblies.

As the inward stroke of the piston assemblies is thus shortened in response to increasing pressure in the scavenger receiver 9 as just mentioned, the innermost unseated position of valve 437 will shift in the direction of its seat to a corresponding extent to so cooperate with the changing positions of said seat that the intermittent opening of said valve will be of such duration as to so regulate the reduction in pressure in chamber 391, with respect to the reducing mean direct bounce chamber pressure in chamber 390, that the extent of opening of valve 383 as controlled by diaphragm 389 will be such that the reduction in pressure in the direct bounce chambers 19 will be so limited with respect to the coacting and opposing forces above mentioned, that the inner dead points of the piston assemblies will progressively change outwardly in substantial proportion to the increase in pressure in the scavenger receiver 9, so as to maintain substantially constant, the final compression pressure in power chamber 6, and also reduce in like proportion the length of the inward stroke of the piston assemblies and the output of compressed air.

When the output of compressed air and motive gas by the generator 1 is increased to a degree which equals the consumption thereof, the pressure of air in the scavenger receiver 9 will become substantially constant. As a result, movement of diaphragm 411 and of the seat for valve 437 will cease, whereupon the stroke of the piston assemblies in the inward direction will further shorten just sufficiently to permit sufficient further change in the innermost unseated position of valve 437 toward its seat to so reduce the length of time which said valve is unseated on each inward stroke of the piston assemblies as to permit sufficient increase in pressure in diaphragm chamber 391 to overcome the opposing mean direct bounce chamber pressure in chamber 390 and deflect diaphragm 389 in the direction of the latter chamber to close valve 383 and prevent further release of air from the direct bounce chambers 19.

With the amount of air now bottled up in the direct bounce chambers 19 adjusted in accordance with the coacting and opposing forces above described, the piston assemblies will continue to operate at the shortened inward stroke corresponding to the pressure in the scavenger receiver 9.

If the consumption of motive gas is reduced the pressure in the scavenger receiver 9 will increase and in response thereto the diaphragm 411 will move further against spring 422 to correspondingly change the position of the seat for valve 437, whereupon the resulting reduction in pressure in diaphragm chamber 391 will permit the mean direct bounce chamber pressure in chamber 390 to actuate diaphragm 389 to open valve 383 for reducing the amount of air in the direct bounce chambers 19 in accordance with the in-

crease in pressure in the scavenger receiver 9. When the pressure in the scavenger receiver again becomes stable upon shortening of the inward stroke of the piston assemblies, in proportion to the reduced consumption of motive gas, the valve 383 will again close to hold constant the amount of air in the direct bounce chambers 19, in the same manner as above described.

On the other hand, if the consumption of motive gas increases, the resultant reduction in pressure in the scavenger receiver 9 and hence in diaphragm chamber 413 will permit spring 422 to move diaphragm 411 outwardly to permit a corresponding movement of the seat for valve 437 in the direction of said valve, whereby the time which said valve is open for each inward stroke of the piston assembly will be reduced to permit an increase in pressure in diaphragm chamber 391. Upon such increase diaphragm 389 will be deflected in the direction of chamber 390 to actuate the seated valve 383 and plunger 377 to open valve 374 whereupon the piston 366 will open valve 355 for supplying air to the direct bounce chambers 19. The consequent increase in energy of the air in the direct bounce chambers 19 will in turn lengthen the stroke of the piston assemblies in an inward direction for increasing the output of compressed air and hence of motive gas, and this operation will continue until said output equals the consumption, at which time the scavenger receiver pressure will again become stable. Movement of diaphragm 411 will then cease and the change in stroke of the piston assemblies will then continue only until the time of opening of valve 437 is so regulated that the pressure in diaphragm chamber 391 will be overcome by the mean direct bounce chamber pressure in chamber 390 to permit the latter pressure to deflect the diaphragm 391 to permit closing of valve 376 and hence cause operation of piston 363 to close valve 355, for thereby again bottling up an amount of air in the direct bounce chambers 19 corresponding to the pressure in the scavenger receiver 9.

In the above description of the initial charging of the scavenger receiver 9, and of the operation of the apparatus in response to reduction and increase in consumption of motive gas, the change in stroke of the piston assemblies was described as being initiated by change in position of diaphragm 411 in response to the change in pressure in said receiver. It is desired to point out, however, that such operation may be initiated by a change in inward stroke of the piston assemblies resulting from the change in pressure in the scavenger receiver being reflected in a like change in pressure in the fresh air change in power chamber 6, or by the simultaneous response of diaphragm 411 and change in stroke of the piston assemblies, it being noted, however, that for any change in position in diaphragm 411 and of the seat for valve 437, said valve will have to be unseated for a corresponding length of time to obtain the proper amount of air in the direct bounce chambers 19 to limit the inward stroke of the piston assemblies to the proper and corresponding dead points.

If upon a reduction in pressure in the scanvenger receiver 9 the inward stroke of the piston assemblies increases ahead of response of diaphragm 411, the time which valve 437 will be opened will be increased for reducing the pressure in chamber 391 and hence the amount of air in the direct bounce chambers which will act to shorten the inward stroke of the piston. This is just the reverse of what happens if diaphragm 411 responds first, but the final result will be the same, for upon response of diaphragm 411 to reducing pressure in the scavenger receiver 9, the time of opening of valve 437 will be reduced to cause an increase in the amount of air in the direct bounce chambers 19 for increasing the inward stroke of the piston assemblies in proportion to the reduction in pressure in the scavenger receiver.

On the other hand, if the inward stroke of the piston assemblies tends to reduce ahead of response of diaphragm 411 to increasing pressure of fluid in the scavenger receiver, such will result in shortening of the length of time which valve 437 will be open and cause an increase in pressure in diaphragm chamber 391 and a corresponding increase in the amount of air in the direct bounce chambers 19 to prevent undue shortening of the stroke. This also is just the reverse of the operation when the diaphragm 411 responds first, but the final result will be the same, for when the diaphragm 411 responds to the increasing pressure of fluid in chamber 413 the time of opening of valve 437 will be increased, as before described, to cause a reduction in the amount of air in the direct bounce chambers 19 for reducing the inward stroke of the piston assemblies according to the increase in pressure in the scavenger receiver 9.

Thus regardless of whether the diaphragm 411 responds to a change in pressure in the scavenger receiver 9 ahead of change in inward stroke of the piston assemblies, or vice versa, or whether both changes occur in unison, the amount of air in the direct bounce chambers 19 will be properly regulated as above described to adjust the inward stroke of the piston assemblies in substantial proportion to the pressure in the scavenger receiver 9 and to at the same time maintain substantially constant the final compression pressure in power chamber 6.

It will be noted that the valve 437 as controlled by the piston assemblies will maintain the inner dead points of the piston assemblies within very close limits, said dead points being determined by the pressure in the scavenger receiver 9 and hence the position of diaphragm 411 and the amount of air in the direct bounce chambers 19.

In gas generators of this type there may be leakage of air to or from the direct bounce chambers 19 which would tend to destroy the relation between the coacting and opposing forces above described. Such destruction of relation of forces cannot occur, however, in the present structure since in case of leakage either to or from the direct bounce chambers 19, a corresponding change in the mean direct bounce chamber pressure in diaphragm chamber 390 will operate or permit operation of the diaphragm 389 to either open valve 383 or valve 376, as the case may be, for releasing air from or supplying air to the direct bounce chambers 19 as required to compensate for such leakage and thereby maintain the amount of air in said chambers in the proper relation to the coacting and opposing forces on the piston assemblies, above mentioned.

From the above description it will now be seen that the direct bounce governor device 4 will automatically adjust the amount or quantity of air in the direct bounce chambers 19 as required to maintain the proper relation between the above described coacting and opposing forces on

the piston assemblies, for any pressure in the scavenger receiver.

While the control of fuel to combustion chamber 6 constitutes no part of the present invention, it is desired to point out that, for the purpose of simplicity in the above description, it was assumed that the supply of fuel was constant. However, in practice the supply of fuel to the generator may be varied in proportion to the consumption of motive gas as governed by the load on the turbine operated thereby. The outer dead points of the piston assemblies are determined by the amount of fuel supplied to power chamber 6, said outer dead points being moved out upon an increase in fuel supply and in upon a reduction in fuel supply. Moreover the amount of air retained in the clearance space of the air compressing chambers 15, and the energy thereof for urging the piston assemblies toward their inner dead points reduces as the outer dead points of the piston assemblies move out and increases with inward movement of said outer dead points. It is therefore necessary that the amount of air in the direct bounce chambers 19 be varied in accordance with the fuel supply to the generator and the outer dead points of the piston assemblies, and the direct bounce governor device 4 will automatically adjust said amount of air to this varying condition so as to maintain desired operation of the generator.

For instance, if the fuel supply is increased resulting in moving out of the outer dead points of the piston assemblies, the amount of air retained in the clearance space in the air compressing chambers 15 will be correspondingly less, so that the following inward stroke of the piston assemblies will be correspondingly reduced. This will result in the valve 437 being opened for a shorter period of time and the resulting increase in pressure in diaphragm chamber 391 will cause a corresponding increase in the amount of air in the direct bounce chambers 19 so that, on the next or a succeeding inward stroke, the piston assemblies will be moved to their inner dead points corresponding to the pressure in the scavenger receiver.

On the other hand, if the amount of fuel is reduced and the outward stroke of the piston assemblies is shortened, the excess air in the direct bounce chambers 19 at the time of such reduction, together with the greater amount of air in the clearance space in the air compressing chambers 15 will cause the piston assemblies to overtravel their inner dead points which will lengthen the time which valve 437 is open so as to correspondingly reduce the pressure in chamber 391 and the amount of air in the direct bounce chambers 19 to reduce the stroke of the piston assemblies to that corresponding to the pressure in the scavenger 9.

It will thus be seen that while the outer dead points of the piston assemblies will vary according to the amount of fuel supplied to power chamber 6, the direct bounce governor device 4 will automatically regulate the amount of air in the direct bounce chambers 19 as required to compensate for change in energy of the compressed air in the clearance space of the air compressing chambers 15 in order to maintain the inner dead points of the piston assemblies in the proper relation to the pressure in the scavenger receiver 9.

In the operation above described it was assumed that the operator's control lever 137 was in the "Normal Running Reverse Bounce Pressure" position maintaining in the reverse bounce chambers 13 a chosen amount of air the energy of which at the inner dead points of the piston assemblies coacted with the power of combustion in power chamber 6 to move the piston assemblies to their outer dead points. With the lever 137 in this position the frequency of reciprocation of the piston assemblies will be substantially constant for any rate of fuel supply to the power chamber 6, although the frequency will vary for different rates of fuel supply in substantial proportion thereto. The frequency of reciprocation of the piston assemblies may however also be varied in proportion to the amount of air provided in the reverse bounce chambers 13 in excess of that provided in the "Normal Running Bounce Chamber Pressure" position.

If it is desired to increase the frequency of reciprocation of the piston assemblies the operator's control lever 137 will be moved out of the "Normal Running Reverse Bounce Pressure" position in the direction of and to any selected position up to the "Maximum Running Reverse Bounce Pressure" position, depending upon the increase in frequency desired.

As the lever 137 is thus operated it will turn the cam 146 relative to the follower 151 and displace said follower and thereby the plunger 104 in a downwardly direction relative to the seated release pilot valve 83 and the plunger 77 and pin 120 connected therewith. As the plunger 104 is thus displaced the pin 120 will open the supply pilot valve 117 and then the supply valve 113 to permit flow of fluid under pressure from the supply pipe 125 and supply valve chamber 111 to chamber 63 and thence through passage 64 and pipe 65 to the direct bounce chambers 13. As air is thus supplied to the reverse bounce chambers 13 it will also flow from pipe 14 through the pick-off valve device 53 into pipe 52 and thence into diaphragm chamber 51 of the operator's control device, whereby a substantially constant pressure in the latter chamber will be obtained equal substantially to nearly the maximum in the reverse bounce chambers 13 at the inner ends of the stroke of the piston assemblies.

Now assuming that the operator's control lever 137 is stopped short of the "Maximum Running Reverse Bounce Pressure" position, movement of plunger 104 will also cease, and the increase in pressure in diaphragm chamber 51, in accordance with the increase in the amount of air supplied to the reverse bounce chambers 13, will gradually deflect said diaphragm against spring 68, and permit movement of the supply valve 113 and supply pilot valve 117 by spring 119 with said diaphragm and relative to the plunger 104, until said valves become seated for preventing further supply of fluid under pressure to the reverse bounce chambers 13. The amount of air in the reverse bounce chambers 13 will thereby be adjusted in accordance with the new position of the operator's control lever 137 and the frequency of reciprocation of the piston assemblies will increase in proportion.

If it is desired to further increase the frequency of reciprocation of the piston assemblies the lever 137 will be moved further in the direction of the "Maximum Running Reverse Bounce Pressure" position for correspondingly increasing the amount of air in the reverse bounce chambers 13. A maximum amount of air may be provided in the reverse bounce chambers 13, for obtaining a maximum frequency of reciprocation of the piston assemblies, upon movement

of the lever 137 into the "Maximum Running Reverse Bounce Pressure" position.

If it is desired to reduce the frequency of reciprocation of the piston assemblies, assuming that the operator's control lever 137 is disposed out of the "Normal Running Reverse Bounce Pressure" position in the direction of the "Maximum Running Reverse Bounce Pressure" position, said lever may be returned in the direction of the former position to a position to provide a desired reduced frequency of operation, and in response to this operation of said lever the cam 146 will be so adjusted as to permit the bias spring 133 to actuate the plunger 104 in the direction of said cam. The seated supply valve 113 and seated supply pilot valve 117 will move with the plunger 104 and thus permit spring 91 acting on the release pilot valve 83 to move said pilot valve and the plunger 77 along with the pin 120 and plunger 104 relative to the post 69 connected to the diaphragm 48. This movement of the release pilot valve 83 will therefore be relative to and out of contact with the seat member 85 whereupon fluid under pressure will be vented from chamber 74 within the cylinder 70 at a rate exceeding the rate of supply through the port 75. When the pressure of fluid in chamber 74 is thus sufficiently reduced the pressure of fluid in chamber 63 acting on the opposite side of the release valve 71 will unseat said valve from the end of sleeve 59 against the opposing force of spring 73 whereupon fluid under pressure will be released from chamber 63, and thereby from the reverse bounce chambers 13, to the interior of sleeve 59 and thence through port 72, chamber 71 and passage 67 to atmosphere.

As air thus released from the reverse bounce chambers 13 the mean reverse bounce chamber pressure effective in diaphragm chamber 51 will correspondingly reduce which will permit spring 68 to deflect the diaphragm 48 in the direction of chamber 51. Now assuming that movement of the operator's control handle 137 and thereby of the release pilot valve 83 has ceased, this deflection of diaphragm 48 and of the seat member 85 will be relative to the release pilot valve 83 and finally said seat member will contact said pilot valve in a position of the diaphragm 48 corresponding to that of the operator's control lever 137. When the release pilot valve 83 is thus seated the flow of fluid under pressure from chamber 63 through port 75 into chamber 74 of the cylinder 70 will increase the pressure in said chamber to a degree to permit spring 73 to seat the release valve 71 against the end of sleeve 59 for preventing further release of air from the reverse bounce chambers 13. The amount of air in the reverse bounce chambers 13 will thus reduce to a degree corresponding to the new position of the operator's control lever 137, whereby the frequency of reciprocation of the piston assemblies will also reduce to correspond to said new position of said lever.

If it is desired to further reduce the frequency of operation of the piston assemblies the lever 137 may be moved further in the direction of "Normal Running Reverse Bounce Pressure" position whereupon the pressure of fluid in the reverse bounce chambers 13 will be correspondingly reduced. If the lever 137 is returned to the "Normal Running Bounce Pressure" position the amount of air in the reverse bounce chambers 13 will be reduced to a minimum employed therein during running of the generator.

It will now be seen that by suitable adjustment of the operator's control lever between the "Normal Running Reverse Bounce Pressure" position and the "Maximum Running Reverse Bounce Pressure" position any desired amount or quantity of air may be provided in the reverse bounce chambers 13, between chosen minimum and maximum limits, for obtaining a desired, corresponding frequency of reciprocation of the piston assemblies.

Stopping of generator 1

Usually the generator will be stopped by merely cutting off the supply of fuel. If desired, however, it may be stopped by moving the operator's control lever 137 to "Stop" position which will permit the bias spring 133 to move the plunger 104 to a position in which the release pilot valve 83 will be open when the diaphragm follower 54 is in contact with the casing partition wall 60. Upon opening the release pilot valve 83, the release valve 71 will initially open, as above described, to quickly release air from the reverse bounce chambers 13, and when a substantial, complete release is obtained the spring 73 will seat said release valve whereupon any further release of air from said chambers will occur past the open release pilot valve 83. When the air is thus released from the reverse bounce chambers 13 the stroke of the piston assemblies in the inward direction will immediately increase and open to a greater extent the valve 437 in the direct bounce governor device to cause operation of said device to correspondingly reduce the pressure in the direct bounce chambers 19, but the release of air from the reverse bounce chambers 13 will be at such a rapid rate that the direct bounce governor device 4 will not be able to correspondingly adjust the amount of air in the direct bounce chambers 19 fast enough to maintain the necessary relation between the opposing and coacting forces above mentioned to continue operation of the generator, whereupon the generator will promptly stop.

After the generator 1 is stopped with the reverse bounce chambers 13 open to atmosphere, the pressure in the direct bounce chambers 19 will move the piston assemblies inwardly so as to open valve 437 in the direct bounce governor device 4 whereupon fluid from the diaphragm chamber 391 will flow past said valve to the direct bounce chambers 19, and this flow will continue until the pressure of fluid in the direct bounce chambers 19 and in diaphragm chamber 390 is increased to a degree sufficient to overcome the opposing pressure in chamber 391 on the diaphragm 389, whereupon said diaphragm will be deflected in the direction of the left hand to open valve 383 whereupon further increase in pressure in the direct bounce chambers 19 will be prevented, since the supply of fluid to diaphragm chamber 391 past the valve 437 will be dissipated, along with the fluid under pressure in the direct bounce chambers 19, to atmosphere past the valve 383, as hereinbefore described.

EMERGENCY OR COLD WEATHER STARTING

When the atmospheric temperature is relatively low and the generator 1 is therefore cold, the cold lubricant therein may slow down the initial movement of the piston assemblies to such a degree that in starting, as before described, the vent valves 25 will close too soon, with respect to the initial inward stroke of the pistons 12, 12a so as to trap in the reverse bounce chambers 13 an excess amount of air with respect to that provided

in the direct bounce chambers 19 by operation of the feed valve device 36, as a result of which, the piston assemblies will stop after two or three cycles of operation. To avoid this stopping of the generator during starting thereof under low temperature conditions it is necessary to maintain the vent valves 25 open, after they have been opened for venting the air from the reverse bounce chambers, until after the generator has warmed up.

To thus maintain the vent valves 25 open during the warming-up of the generator under cold weather conditions the valve seating element 463 associated with the dump exhaust valve device 40 will be screwed into contact with the valve stem 312 and actuate said stem to seat the valve 314, and the cut-out valve 461 will be operated to establish communication between pipe 460 and pipe 462 for supplying fluid under pressure from the feed valve device 459 to the dump supply valve device 39. The operator's control device 3 will then be operated to cause the generator 1 to start in the same manner as before described, that is, by initially supplying fluid under pressure to the reverse bounce chambers 13 to move the piston assemblies to their outermost positions, followed by charging of the direct bounce chambers 32 with fluid under pressure, and finally opening of the vent valves 25 for releasing the air from the reverse bounce chambers 13. With the valve 461 open and the closing element 463 of the dump exhaust valve device 40 operated, the vent valves 25 upon being opened to permit the initial inward stroke of the piston assemblies will then be maintained open by fluid under pressure from the feed valve device 459.

It will therefore be seen that after starting, and while warming up the generator 1, under low temperature conditions, the reverse bounce chambers 13 will be maintained open to atmosphere. If the operator's control lever 137 is left in "Start" position after the generator is started and is running the fluid under pressure supplied to the reverse bounce chambers 13 thereby will be merely dissipated to atmosphere. This waste of fluid under pressure may be avoided however, if desired, by moving the lever 137 from "Start" position to the opposite end of the short portion 208 of slot 206.

After the generator is properly warmed up the cut-out valve 461 will be closed to cut off further supply of fluid under pressure to hold the vent valves 25 open, and the valve seating element 324 will be backed off to permit the dump exhaust valve device 40 to operate on the first succeeding inward stroke of the piston assemblies to vent the fluid under pressure from chambers 26 in the starting valve devices to permit closure of the vent valves 25. This closing of the vent valves after the generator has been running for warming up will promptly destroy the proper relation between the coacting and opposing forces on the piston assemblies, as a result of which the piston assemblies will stop. If upon stopping the operator's control lever 137 is still in "Start" position, the apparatus will immediately operate automatically, in the same manner as hereinbefore described under "Normal Starting of Gas Generator 1" to cause the generator to restart and then run in the same manner as hereinbefore described. If the operator's control lever is not in "Start" position when the generator stops after warming up, then movement to "Start" position will cause starting and running of the generator as previously described.

SUMMARY

From the above description it will now be seen that I have provided a control apparatus for a free piston gas generator embodying a single operator's control device for controlling starting and/or running of said generator after starting. The operator's control device by controlling the energy in the reverse bounce chambers in the generator, in combination with the automatically operative direct bounce governor device for controlling energy in the direct bounce chambers of said generator will automatically regulate the output of motive gas by the generator in proportion to the consumption thereof. The operator's control device by its control of the amount of air in the reverse bounce chambers also provides for varying the frequency of reciprocation of the free piston assemblies. In addition to the above, I also provide apparatus necessary for starting the generator under temperature conditions which may be considered lower than normal.

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

1. 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 pistons 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, means operative by said pistons in said chosen position to effect operation of said second valve means, vent valve means for venting fluid under pressure from said reverse bounce chamber, and means operative in response to a chosen increase in pressure in said cushion means to effect operation of said vent valve means.

2. 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 pistons in the opposite direction, said apparatus comprising first valve means for supplying fluid under pressure to said reverse bounce chamber to effect movement of said pistons to a chosen position in the first named direction, second valve means for supplying fluid under pressure to said cushion means, means operative by said pistons in said chosen position to effect operation of said second valve means, vent valve means operative by fluid under pressure for venting fluid under pressure from said reverse bounce chamber, a third valve means for supplying fluid under pressure to said vent valve means for effecting operation of said vent valve means, and means operative in response to a chosen increase in pressure in said cushion means to effect operation of said third valve means.

3. 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 pistons in the opposite direction, said apparatus comprising first valve means for supplying fluid under pressure to said reverse bounce chamber to effect movement of said pistons to a chosen position in the first named direction, second valve means for supplying fluid under pressure to said cushion means, means operative by said pistons in said chosen position to effect operation of said second valve means, vent valve means operative by fluid under pressure for venting fluid under pressure from said reverse bounce chamber, a third valve means for supplying fluid under pressure to said vent valve means, and means operative in response to a chosen increase in pressure in said cushion means to effect operation of said second valve means to cut off said supply of fluid under pressure to said cushion means and to also effect operation of said third valve means.

4. 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 pistons in the opposite direction, said apparatus comprising a manually controlled 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, vent valve means for venting the fluid under pressure from said reverse bounce chamber, and means responsive to operation of said first valve means for automatically effecting operation of said second and vent valve means in the order named.

5. 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 pistons in the opposite direction, said apparatus comprising manually operative first valve means for supplying fluid under pressure to said reverse bounce chamber to effect movement of said pistons in the first named direction, a second valve means for supplying fluid under pressure to said cushion means, means operative by said pistons near the end of their stroke in said first named direction to effect operation of said second 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.

6. 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 pistons 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 operative by said pistons in said chosen position to effect a supply of fluid under pressure to said cushion means, and means operative in response to a chosen increase in pressure in said cushion means to vent the fluid under pressure from said reverse bounce chamber.

7. 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 pistons 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 operative by said pistons in said chosen position to effect a supply of fluid under pressure to said cushion means and to cut off said supply in all other positions of said pistons, check valve means for holding fluid under pressure in said cushion means upon cutting off of the supply of fluid under pressure thereto, vent valve means for venting fluid under pressure from said reverse bounce chamber, and means for effecting operation of said vent valve means upon a chosen increase in pressure in said cushion means.

8. 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 pistons 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 operative by said pistons in said chosen position to effect a supply of fluid under pressure to said cushion means and in all other positions of said piston to cut off said supply, check valve means for holding fluid under pressure in said cushion means upon cutting off of the supply thereto, vent valve means controlling a fluid venting communication from said reverse bounce chamber, means operative in response to a chosen increase in pressure in said cushion means to effect operation of said vent valve means to open said communication, and means operative in response to a certain movement of said pistons from said extreme position in said opposite direction to effect operation of said vent valve means to close said venting communication.

9. 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 pistons 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 responsive to movement of said pistons to said chosen position to supply fluid under pressure to said cushion means, vent valve means controlling a fluid venting communication from said reverse bounce chamber, means operative in response to a chosen increase in pressure in said cushion means to effect operation of said vent valve means to open said venting communication, and means responsive to a certain movement of said pistons from said chosen position in said opposite direction to effect operation of said vent valve means to close said venting communication.

10. 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 pistons 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 operative by said pistons only in said chosen position to effect a supply of fluid under pressure to said cushion means, vent valve means controlling a fluid vent communication from said reverse bounce chamber, means operative in response to a chosen increase in pressure in said cushion means to effect operation of said vent valve means to open said communication, and means responsive to a reduction in pressure in said cushion means to a chosen lower degree to effect operation of said vent valve means to close said communication.

11. 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 pistons in the opposite direction, said apparatus comprising an operator's control lever having a "Start" position and means conditioned by said lever in said "Start" position to supply fluid under pressure to said reverse bounce chamber for moving said pistons to a chosen position in the first named direction, valve means responsive to movement of said pistons to said chosen position for supplying fluid under pressure to said cushion means, and means responsive to a chosen increase in pressure in said cushion means to vent fluid under pressure from said reverse bounce chamber.

12. 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 pistons in the opposite direction, said apparatus comprising an operator's control lever having a "Start" position and means conditioned by said lever in said "Start" position to supply fluid under pressure to said reverse bounce chamber for moving said pistons to an extreme position in the first named direction, supply valve means for supplying fluid under pressure to said cushion means, means operable by said pistons in said chosen position to effect operation of said supply valve means and in all other positions of said pistons to render said supply valve means ineffective to supply fluid under pressure, and means responsive to an increase in pressure in said cushion means to a chosen degree to effect release of fluid under pressure from said reverse bounce chamber.

13. 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 pistons in the opposite direction, said apparatus comprising means for supplying fluid under pressure to said reverse bounce chamber for moving said pistons to a chosen position in the first named direction, vent valve means operable by fluid under pressure to vent the fluid under pressure from said reverse bounce chamber, dump supply valve means controlling a fluid pressure supply communication to said vent valve means and operable by fluid under pressure to close said communication and upon release of fluid under pressure to open said communication, second supply means operable by fluid under pressure for supplying fluid under pressure to said cushion means and to said dump supply valve means for supply to said vent valve means, timing means operable by said pistons in said chosen position to effect supply of fluid under pressure to said second supply means and in all other positions of said pistons to cut off the supply of fluid under pressure to said second supply means, sequence means normally supplying fluid under pressure to operate said dump supply valve means and responsive to a chosen increase in pressure in said cushion means to release the fluid under pressure from said dump supply valve means, and dump exhaust means operable in response to a chosen reduction in pressure in said cushion means to release fluid under pressure from said vent valve means.

14. 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 pistons in the opposite direction, said apparatus comprising means for supplying fluid under pressure to said reverse bounce chamber for

moving said pistons to a chosen position in the first named direction, vent valve means operable by fluid under pressure to open an atmospheric vent from said chamber and upon release of said fluid pressure to close said vent, supply valve means operable by fluid under pressure to supply fluid under pressure to said cushion means and to a communication for conveying fluid under pressure to said vent valve means and operable in response to release of said fluid under pressure to cut off such supply of fluid under pressure, choke means for restricting flow of fluid under pressure to said cushion means but not to said communication, a check valve for preventing back-flow of fluid from said cushion means, another check valve for preventing back-flow of fluid through said communication, timing means operative by said piston in said chosen position to supply fluid under pressure to effect operation of said supply valve means and at all other times to release such fluid under pressure from said supply valve means, dump supply valve means operable by fluid under pressure to close said communication and upon the release of fluid under pressure to open said communication, sequence valve means for normally supplying fluid under pressure to operate said dump supply valve means and communicating with and operable in response to a chosen increase in pressure in said cushion means to release the fluid under pressure from said dump supply valve means, a check valve in the communication between said cushion means and sequence valve means for preventing back flow of fluid under pressure in the direction to said cushion means, a dump exhaust valve controlled by pressure in said cushion means and operable upon a reduction in such pressure to a chosen degree to release fluid under pressure from said vent valve means, and means for releasing fluid under pressure from said sequence valve means at the outlet side of the last named check valve.

15. 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 pistons in the opposite direction, said apparatus comprising an operator's control lever having a "Start" position and a "Run" position, means operable by said lever in both of said positions to effect a supply of fluid under pressure to said reverse bounce chamber, starting means operable by said lever in said "Start" position to supply fluid under pressure and in said "Run" position to release such fluid under pressure, vent valve means operable by fluid under pressure to open an atmospheric vent from said reverse bounce chamber and upon release of such fluid under pressure to close said vent, dump supply valve means operable by fluid under pressure to close a fluid pressure supply communication to said vent valve means and upon release of such fluid under pressure to open said communication, sequence valve means normally connecting said dump supply valve means to said starting means, cushion supply valve means operable by fluid under pressure to supply fluid under pressure to said cushion means, said sequence valve means and also to said dump supply valve means for supply through said communication to said vent valve means and operable upon release of such fluid under pressure to cut off such supply, choke means for restricting flow of fluid under pressure to said cushion means and said sequence valve means, a check valve for preventing back flow of fluid under pressure from said cushion means and sequence valve means, a check valve for preventing back flow of fluid under pressure through said communication to said cushion supply valve means, another check valve for preventing back flow of fluid under pressure from said sequence means to said cushion means, timing valve means operable by said pistons in said chosen position to supply fluid under pressure to actuate said supply valve means and to cut off said supply when out of said chosen position, said sequence valve means comprising means operable in response to a chosen increase in pressure in said cushion means to disconnect said dump supply valve means from said starting means and to release fluid under pressure from said dump supply valve means, dump exhaust valve means controlled by pressure of fluid in said cushion means and operative in response to a reduction in such pressure to a chosen low degree to release fluid under pressure from said vent valve means, and valve means operable by fluid under pressure supplied by said starting means to close a vent from the connection between said sequence valve means and the last named check valve and operable in response to release of fluid under pressure to open the last named vent.

16. 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 pistons 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, vent valve means operably by fluid under pressure to open a vent communication from said reverse bounce chamber and upon release of such fluid under pressure to close said vent communication, a second valve means operable in said chosen position of said pistons to supply fluid under pressure to said cushion means and to cut off said supply in all other positions of said pistons, dump supply valve means for supplying fluid under pressure from said second valve means to said vent valve means, sequence valve means normally effecting operation of said dump supply valve means to prevent supply of fluid under pressure to said vent valve means and operative upon a chosen increase in pressure in said cushion means to effect operation of said dump supply valve means to supply fluid under pressure from said second valve means to said vent valve means, dump exhaust valve means operative in response to a chosen reduction in pressure in said cushion means to open a vent communication from said vent valve means, manually adjustable means for preventing operation of said dump exhaust valve to open said vent communication, a source of fluid under pressure, and manually adjustable means for opening and closing communication between said source and said vent valve means.

17. An apparatus for controlling running of an internal combustion free piston machine in accordance with the pressure of air in a receiver and having a power piston, a rigidly connected air compressing piston operable by said power piston on an outward stroke to compress air into said receiver, and air cushion means operable by said power piston on said outward stroke to compress air for moving said pistons on an inward stroke on completion of the power and air compressing stroke of said pistons, said apparatus comprising valve means for supplying air to and releasing air from said cushion means, pressure means adjustable in accordance with pressure of air in said receiver, and means responsive to movement of said pistons on said inward stroke cooperative with said pressure means to effect operation of said valve means to, respectively, release air from or supply air to said cushion means for varying the quantity of air therein in a chosen relation to the pressure of air in said receiver.

18. An apparatus for controlling running of an internal combustion free piston machine in accordance with the pressure of air in a receiver and having a power piston, a rigidly connected air compressing piston operable by said power piston on an outward stroke to compress air into said receiver, and air cushion means operable by said power piston on said outward stroke to compress air for moving said pistons on an inward stroke on completion of the power and air compressing stroke of said pistons, said apparatus comprising valve structure responsive to a reduction in pressure of fluid in a control chamber to release air from said cushion means and responsive to an increase in said pressure of fluid in said control chamber to supply air to said cushion means, valve means for regulating the pressure of fluid in said control chamber, and means responsive jointly to pressure of air in said receiver and movement of said pistons on said inward stroke for actuating said valve means for varying the pressure of fluid in said control chamber in substantial inverse proportion to the pressure in said receiver.

19. An apparatus for controlling running of an internal combustion free piston machine in accordance with the pressure of air in a receiver and having a power piston, a rigidly connected air compressing piston operable by said power piston on an outward stroke to compress air into said receiver, and air cushion means operable by said power piston on said outward stroke to compress air for moving said pistons on an inward stroke on completion of the power and air compressing stroke of said pistons, said apparatus comprising valve structure responsive to a reduction in pressure of fluid in a control chamber to release air from said cushion means and responsive to an increase in pressure of fluid in said control chamber to supply air to said cushion means, valve means for regulating pressure of fluid in said control chamber, pressure means responsive to an increase or decrease in pressure of air in said receiver, and means responsive to movement of said pistons on said inward stroke cooperative with said pressure means for actuating said valve means to vary the pressure of fluid in said control chamber in substantial inverse proportion to the pressure of air in said receiver.

20. An apparatus for controlling running of an internal combustion free piston machine in accordance with the pressure of air in a receiver and having a power piston, a rigidly connected air compressing piston operable by said power piston on an outward stroke to compress air into said receiver, an air cushion means operable by said power piston on said outward stroke to compress air for moving said pistons on an inward stroke on completion of the power and air compressing stroke of said pistons, said apparatus comprising valve structure responsive to a reduction in pressure of fluid in a control chamber to release air from said cushion means and responsive to an increase in pressure of fluid in said control chamber to supply air to said cushion means, valve means comprising two relatively movable elements for controlling pressure of air in said control chamber, pressure responsive means responsive to pressure of air in said receiver for controlling one of said elements, and means operable by said pistons near the end of said inward stroke for controlling the other element for thereby varying the pressure of fluid in said control chamber in substantial inverse proportion to the pressure of air in said receiver.

21. An apparatus for controlling running of an internal combustion free piston gas generator having an air compressing piston for compressing air into a scavenger receiver, a power piston rigidly connected to said air compressing piston and cooperative with a power cylinder for operating the latter piston on an outward air compressing stroke of said pistons, means for scavenging and charging said power chamber by air from said receiver, and air cushion means operable by said power piston on said outward stroke to compress air for moving said pistons on an inward stroke upon completion of said outward stroke, said apparatus comprising valve means for opening and closing fluid pressure supply and fluid pressure release communications to and from said cushion means, pressure responsive means adjustable in accordance with pressure of air in said receiver, cooperating means responsive to movement of said pistons near the end of said inward stroke, and means controlled jointly by said pressure responsive means and cooperating means constructed and arranged for effecting operation of said valve means to so control said communications as to vary the amount of air in said cushion means in such relation to the pressure in said receiver as to reduce said inward stroke of said pistons in substantial proportion to the increase in pressure in said receiver.

22. An apparatus for controlling running of an internal combustion free piston gas generator having an air compressing piston for compressing air into a scavenger receiver, a power piston rigidly connected to said air compressing piston and cooperative with a power cylinder for operating the latter piston on an outward air compressing stroke of said pistons, means for scavenging and charging said power chamber by air from said receiver, and air cushion means operable by said power piston on said outward stroke to compress air for moving said pistons on an inward stroke upon completion of said outward stroke, said apparatus comprising means responsive to a reduction or increase in pressure of fluid in a control chamber to respectively reduce or increase the quantity of air in said cushion means, means providing a constant restricted supply of fluid under pressure to said control chamber, valve means comprising cooperating valve and seat elements for releasing fluid from said control chamber to vary the pressure of fluid therein in accordance with the length of time said elements are unseated one from the other, pressure responsive means adjustable in response to increasing or decreasing

pressure of air in said receiver to adjust one of said elements in, respectively, a direction out of or toward seating cooperation with the other element, and means responsive to movement of said pistons at substantially the end of said inward stroke to move said other element in a direction away from seating cooperation with said one element.

23. An apparatus for controlling running of an internal combustion free piston gas generator having an air compressing piston for compressing air into a scavenger receiver, a power piston rigidly connected to said air compressing piston and cooperative with a power cylinder for operating the latter piston on an outward air compressing stroke of said pistons, means for scavenging and charging said power chamber by air from said receiver, and air cushion means operable by said power piston on said outward stroke to compress air for moving said pistons on an inward stroke upon completion of said outward stroke, said apparatus comprising movable abutment means subject to pressure of fluid in a control chamber, means providing on said abutment means a mean of the pressure in said cushion means which opposes pressure of fluid in said control chamber, valve means operable by said abutment means upon the pressure of fluid in said control chamber overcoming the opposing mean pressure of said cushion means to supply air to said cushion means and upon said mean pressure overcoming that in said control chamber to release air from said cushion means and when the pressure in said control chamber substantially balances said mean pressure to bottle up the air in said cushion means, and valve means responsive to the pressure in said receiver and movement of said pistons to substantially the dead point thereof at the end of said inward stroke to vary the pressure of fluid in said control chamber in substantial inverse proportion to the pressure of fluid in said receiver.

24. An apparatus for controlling running of an internal combustion free piston gas generator having an air compressing piston for compressing air into a scavenger receiver, a power piston rigidly connected to said air compressing piston and cooperative with a power cylinder for operating the latter piston on an outward air compressing stroke of said pistons, means for scavenging and charging said power chamber by air from said receiver, and air cushion means operable by said power piston on said outward stroke to compress air for moving said pistons on an inward stroke upon completion of said outward stroke, said apparatus comprising a valve seat element and a valve element for said seat, pressure means responsive to an increase in pressure in said receiver to unseat one of said elements from the other to a proportional degree, means operative by said pistons near the end of said inward stroke to unseat said other element from said one element, and means controlled by the length of time which said valve elements are unseated one from the other for varying the quantity of air in said cushion means in substantial inverse proportion to the pressure of fluid in said receiver.

25. An apparatus for controlling running of an internal combustion free piston gas generator having an air compressing piston for compressing air into a scavenger receiver, a power piston rigidly connected to said air compressing piston and cooperative with a power cylinder for operating the latter piston on an outward air compressing stroke of said pistons, means for scavenging and charging said power chamber by air from said receiver, and air cushion means operable by said power piston on said outward stroke to compress air for moving said pistons on an inward stroke upon completion of said outward stroke, said apparatus comprising movable abutment means subject to pressure of fluid in a control chamber, means providing on said abutment means a mean of the pressure in said cushion means which opposes pressure of fluid in said control chamber, valve means operable by said abutment means upon the pressure of fluid in said control chamber overcoming the opposing mean pressure of said cushion means to supply air to said cushion means and upon said mean pressure overcoming that in said control chamber to release air from said cushion means, and when the pressure in said control chamber balances said mean pressure to bottle up the air in said cushion means, means providing a constant restricted flow of fluid under pressure to said control chamber, valve means for releasing fluid under pressure from said control chamber, pressure means adjustable in accordance with the pressure of fluid in said receiver, cooperating means operable by said pistons adjacent the inner dead point of said pistons on their inward stroke, and valve means controlled jointly by said pressure means and cooperating means for releasing fluid under pressure from said control chamber for varying the pressure therein in accordance with the increase in pressure in said receiver and the inner dead point of said pistons.

26. An apparatus for controlling starting and running of an internal combustion free piston machine having an air compressing piston, a rigidly connected power piston operable by power of combustion in a power chamber for moving said air compressing piston on an outward stroke for compressing air into a receiver, and direct bounce air cushion means for moving said pistons on an inward stroke to provide compression ignition in said power chamber, said apparatus comprising means for effecting movement of said pistons on said outward stroke to a chosen position, supply means for charging said cushion means with compressed air, means responsive to outward movement of said pistons to said chosen position to effect operation of said supply means, means responsive to a chosen increase in pressure in said cushion means to release said pistons for movement by compressed air in said cushion means, automatically operative governor means for regulating the quantity of air in said cushion means, valve means for at one time connecting said cushion means to said supply means and for disconnecting it from said governor means and for at another time connecting said cushion means to said governor means and disconnecting it from said supply means, and an operator's control means for controlling said valve means.

27. An apparatus for controlling an internal combustion free piston machine having an air compressing piston, a rigidly connected power piston operable by power of combustion in a power chamber for moving said compressing piston on an outward, air compressing stroke, and direct bounce air cushion means for moving said pistons on an inward stroke to provide compression ignition in said power chamber, said apparatus comprising an operator's control device comprising means for effecting movement of said pistons on said outward stroke to a

chosen position, supply means responsive to movement of said pistons to said chosen position to charge said cushion means with compressed air, means responsive to a chosen increase in pressure in said cushion means to release said pistons for movement by compressed air in said cushion means, automatically operative governor means for regulating quantity of air in said cushion means, structure for at one time connecting said cushion means to said supply means and for disconnecting it from said governor means and for at another time connecting said cushion means to said governor means and disconnecting it from said supply means, said operator's control device also controlling said structure.

28. An apparatus for controlling an internal combustion free piston machine comprising an air compressing piston subject on one side to pressure of air in an air compressing chamber and on the opposite side to pressure of air in a reverse bounce chamber, a rigidly connected power piston operable by products of combustion in a power chamber for moving said compressing piston on an outward stroke for compressing air from said air compressing chamber into a receiver, and direct bounce air cushion means for moving said pistons on an inward stroke to provide compression ignition in said power chamber, said apparatus comprising an operator's control device having "Start" and "Run" positions and comprising means operable in said "Start" position to effect a supply of fluid under pressure to said reverse bounce chamber for moving said pistons on said outward stroke to a position for starting, supply means responsive to movement of said pistons to said position for starting to charge said cushion means with compressed air, and responsive to movement out of said position for starting to cut off the supply of compressed air to said cushion means, means responsive to a chosen increase of pressure in said cushion means to release fluid under pressure from said reverse bounce chamber for rendering said pistons movable on said inward stroke by compressed air in said cushion means, automatically operative governor means for regulating the quantity of air in said cushion means, structure movable to one position for connecting said cushion means to said supply means and for disconnecting it from said governor means and movable to another position for connecting said cushion means to said governor means and disconnecting it from said supply means, said operator's control device also comprising means operative in its "Start" position to effect movement of said structure to its said one position and in its "Run" position to effect movement of said structure to its said other position.

29. An apparatus for controlling starting and running of an internal combustion free piston machine comprising an air compressing piston subject on one side to air pressure in an air compressing chamber and on the opposite side to pressure of air in a reverse bounce chamber, a rigidly connected power piston operable by products of combustion in a power chamber for moving said air compressing piston on an outward, air compressing stroke for compressing air into a receiver, and direct bounce air pressure cushion means for moving said pistons on an inward stroke to provide compression ignition in said power chamber, said apparatus comprising adjustable pressure regulating means for regulating the quantity of air in said reverse bounce chamber, an operator's control lever having a "Start" position and a zone of movement, means responsive to movement of said lever to said "Start" position to effect starting of said machine, and means operable by said lever in said zone to adjust said pressure regulating means in accordance with the position of said lever in said zone.

30. An apparatus for controlling starting and running of an internal combustion free piston machine comprising an air compressing piston subject on one side to air pressure in an air compressing chamber and on the opposite side to pressure of air in a reverse bounce chamber, a rigidly connected power piston operable by products of combustion in a power chamber for moving said air compressing piston on an outward, air compressing stroke for compressing air into a receiver, and direct bounce air pressure cushion means for moving said pistons on an inward stroke to provide compression ignition in said power chamber, said apparatus comprising starting means for said machine, adjustable pressure regulating means for regulating the quantity of air in said reverse bounce chamber, an operator's control lever having a "Start" position for effecting operation of said starting means, said lever also having a "Running" position, and means operable by said lever in both said "Start" and "Running" positions to effect operation of said regulating means to provide a chosen quantity of air in said reverse bounce chamber.

31. An apparatus for controlling running of an internal combustion free piston machine comprising an air compressing piston subject on one side to air pressure in an air compressing chamber and on the opposite side to pressure of air in a reverse bounce chamber, a rigidly connected power piston operable by products of combustion in a power chamber for moving said air compressing piston on an outward, air compressing stroke for compressing air into a receiver, and direct bounce air pressure cushion means for moving said pistons on an inward stroke to provide compression ignition in said power chamber, said apparatus comprising adjustable pressure regulating means for regulating the quantity of air in said reverse bounce chamber, a lever having a zone of movement for adjusting said regulating means, said regulating means comprising a control element subject to fluctuations in pressure in said reverse bounce chamber, a regulating spring, movable abutment means subject to opposing pressures of said regulating spring and pressure of fluid in a control chamber for limiting the quantity of air in said reverse bounce chamber in accordance with the position of said lever in said zone, means subject to pressure of fluid in said reverse bounce chamber counter-acting said pressure of fluid on said control element, and means operable in accordance with fluctuations in pressure in said reverse bounce chamber to provide a substantially constant pressure therefrom in said control chamber.

32. An apparatus for controlling starting and running of an internal combustion free piston machine comprising an air compressing piston subject on one side to air pressure in an air compressing chamber and on the opposite side to pressure of air in a reverse bounce chamber, a rigidly connected power piston operable by products of combustion in a power chamber for moving said air compressing piston on an outward, air compressing stroke for compressing air into a receiver, and direct bounce air pres-

sure cushion means for moving said pistons on an inward stroke to provide compression ignition in said power chamber, said apparatus comprising starting means for said machine, automatically operative direct bounce governor means for varying the quantity of air in said cushion means, adjustable pressure regulating means for regulating the quantity of air in said reverse bounce chamber, an operator's control lever having a "Start" position and a "Run" position, means operable in said "Start" position of said lever to render said direct bounce governor means ineffective and to effect operation of said starting means, and operative in said "Run" position to render said starting means ineffective and said direct bounce governor means effective, and means operable in both said "Start" and "Run" positions of said lever to adjust said pressure regulating means.

33. An apparatus for controlling running of an internal combustion free piston machine having a direct bounce chamber and a reverse bounce chamber, comprising means for varying the quantity of air in one of said chambers, and automatic means for varying the quantity of air in the other of said chambers in accordance with the quantity in said one chamber, said automatic means including an element arranged for operation by said piston near one end of its stroke.

34. An apparatus for controlling running of an internal combustion free piston gas compressor in accordance with pressure of gas in a receiver, said machine having a direct bounce chamber and a reverse bounce chamber, and said apparatus comprising means for varying the quantity of air in one of said chambers, and automatic means for varying the quantity of air in the other chamber in accordance with the quantity of air in said one chamber comprising valve means for supplying air to and releasing air from said other chamber, and means responsive jointly to pressure of gas in said receiver and stroke of said piston for controlling said valve means.

35. An apparatus for controlling running of an internal combustion free piston gas compressor in accordance with pressure of gas in a receiver, said machine having a direct bounce chamber and a reverse bounce chamber, and said apparatus comprising means for varying the quantity of air in one of said chambers, and automatic means for varying the quantity of air in the other chamber in accordance with the quantity of air in said one chamber, comprising valve means for supplying air to and releasing air from said other chamber, pressure responsive means adjustable in accordance with pressure of gas in said receiver, and means responsive to movement of said piston adjacent the end of its gas intake stroke cooperative with said pressure responsive means for controlling said valve means.

36. An apparatus for controlling running of an internal combustion free piston gas compressor in accordance with pressure of gas in a receiver, said machine having a direct bounce chamber and a reverse bounce chamber, and said apparatus comprising means for varying the qauntity of air in one of said chambers, and automatic means for varying the quantity of air in the other chamber in accordance with the quantity of air in said one chamber comprising an air pressure controlled movable abutment, valve means operable in accordance with variations in air pressure on said abutment for regulating the quantity of air in said other chamber, and means for regulating the pressure of air on said abutment comprising pressure sensitive means adjustable in accordance with the pressure of gas in said receiver, and means operable by said piston adjacent the end of its gas intake stroke cooperative with said pressure responsive means for controlling said valve means.

37. An apparatus for controlling running of an internal combustion free piston gas compressor in accordance with pressure of gas in a receiver, said machine having a direct bounce chamber and a reverse bounce chamber, and said apparatus comprising means for varying the quantity of air in one of said chambers, and automatic means for varying the quantity of air in the other chamber in accordance with the quantity of air in said one chamber comprising an air pressure controlled movable abutment, valve means operable in accordance with variations in air pressure on said abutment for regulating the quantity of air in said other chamber, and means for regulating the pressure of air on said abutment comprising pressure sensitive means adjustable in accordance with the pressure of gas in said receiver, and a reciprocable element arranged for operation by said piston adjacent the end of its gas intake stroke cooperative with said pressure sensitive means for controlling said valve means.

38. An apparatus for controlling operation of an internal combustion engine operated free piston machine having a direct bounce chamber, governor means controlled by the free pistons for providing fluid under pressure in said chamber for stabilizing running of said machine and for moving said pistons to their inner dead point upon cutting off of supply of fuel to said engine, and means operable by said pistons at their inner dead points to effect operation of said governor means to released fluid under pressure from said chamber.

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