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FREE-PISTON MACHINES
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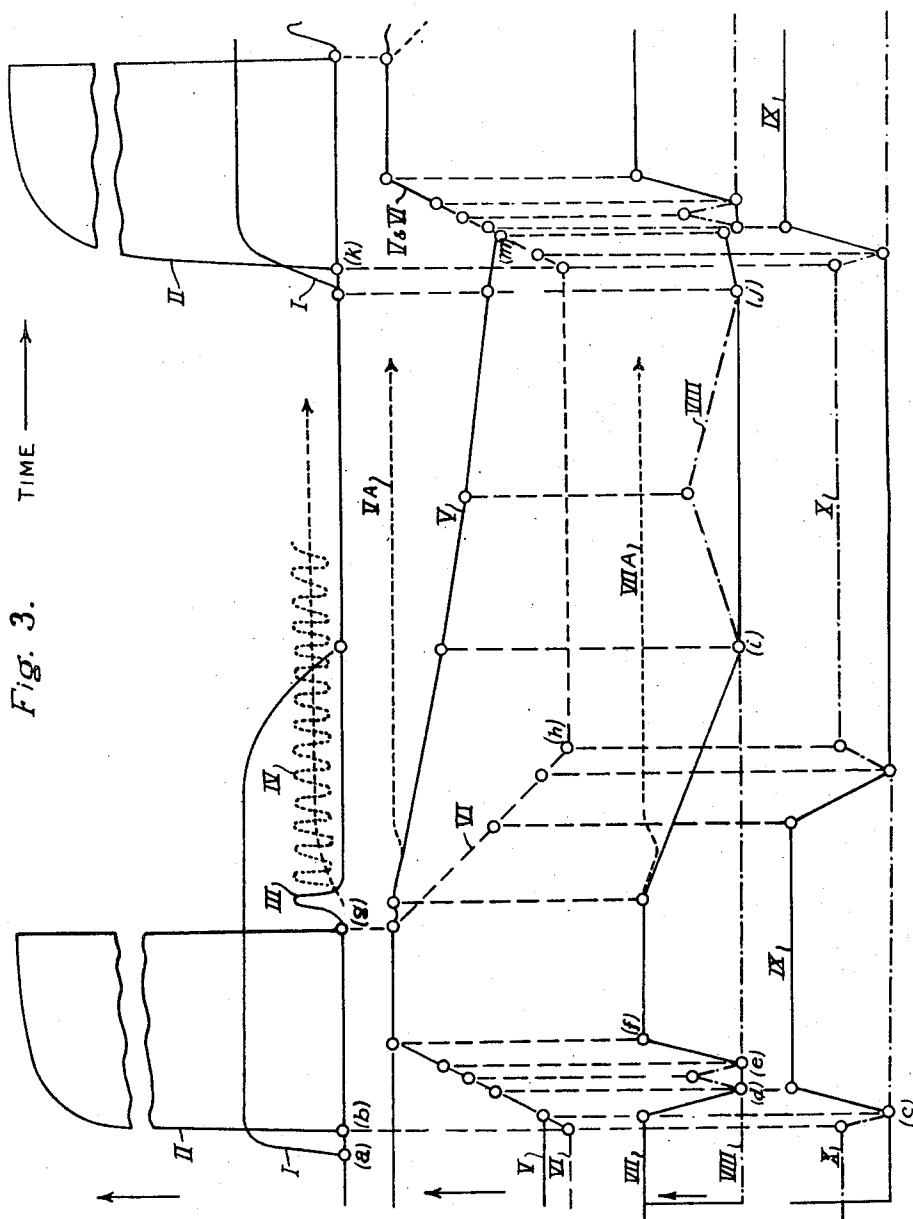
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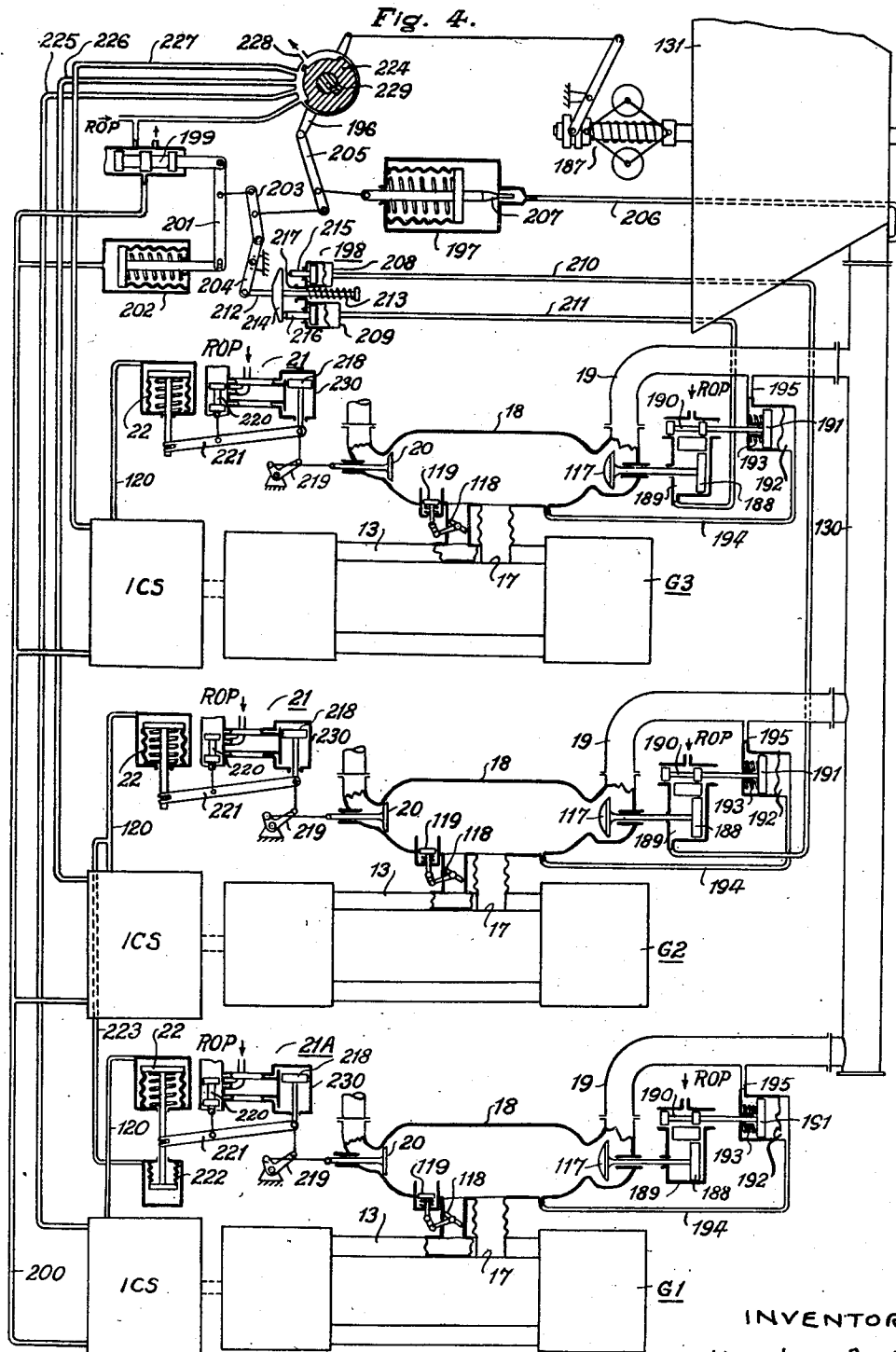
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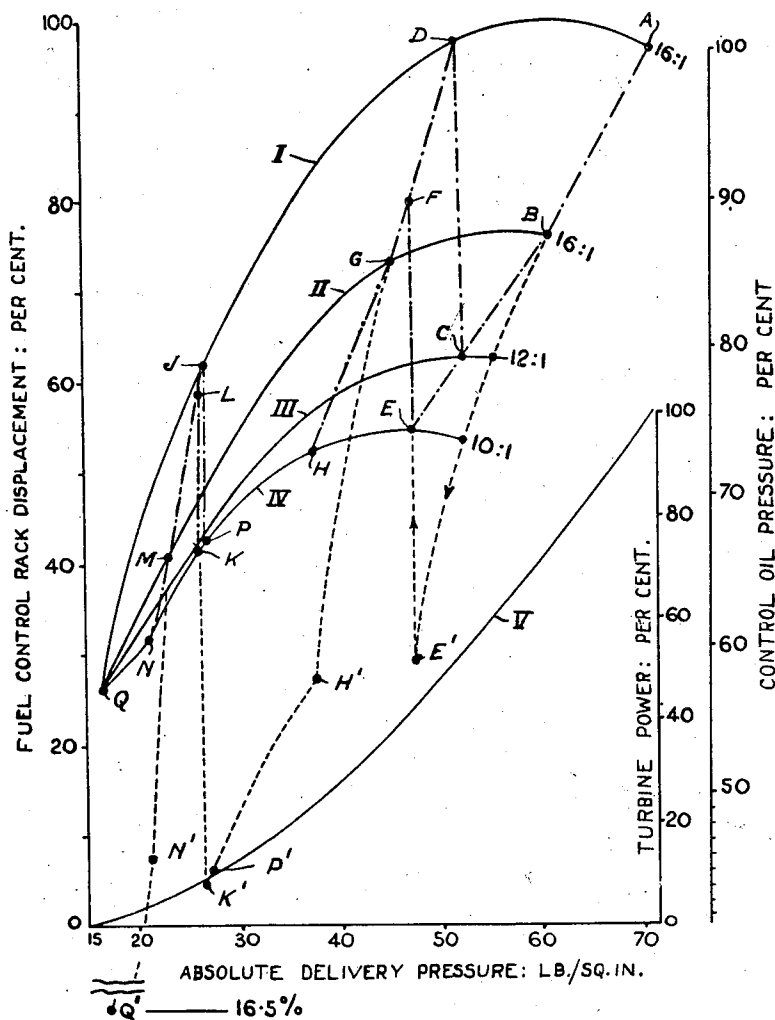
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Fig. 5.



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UNITED STATES PATENT OFFICE

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CONTROL MEANS FOR INTERNAL-COMBUSTION-OPERATED FREE-PISTON MACHINES

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In Great Britain June 1, 1943

20 Claims. (Cl. 230-56)

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This invention relates to internal-combustion-operated air-compressors and gas-generators of the free-piston type.

Such a free-piston machine includes a motor piston and a compressor piston coupled together for operation in unison, this free-piston assembly being unconstrained by any continuously rotatable crank. In a gas-generator, compressed air supplied by the compressor part of the machine is used to scavenge and charge the motor part, which exhausts at superatmospheric pressure, the power gas generated being the mixture of combustion products and excess scavenging air, which may be used, for example, to drive a turbine.

A free-piston machine is started by setting the free-piston assembly at or near the outer limit of its stroke and then accelerating it inwards to compress an air charge in the motor cylinder. Provided the fuel-injection system delivers a charge of fuel into the combustion chamber towards the end of this starting stroke, combustion will take place and the machine will continue to run.

A pneumatic energy accumulator (hereinafter termed a cushion) may be associated with the free-piston assembly, and it takes energy from this assembly during its out-stroke, returning it to the assembly on its in-stroke; the starting stroke is usually effected by suddenly releasing a predetermined quantity of compressed air into the pneumatic cushion which was previously at atmospheric pressure, this air serving as the working fluid of the cushion once the machine has started.

It is therefore apparent that starting a free-piston machine involves the performance of a sequence of operations, and that, if for any reason the machine should fail to start at the starting stroke, this sequence of operations must be repeated before a second attempt can be made.

Where a group of two or more free-piston air-compressors or gas-generators are arranged in parallel to feed a common air or gas main, it is often convenient to control all the free-piston machines by a master control system capable of starting and stopping individual machines as is necessary to meet a varying demand for compressed air or power gas. With such a system, failure of any free-piston machine to start in response to a starting impulse from the master controller will disorganise the control of the plant unless special precautions are taken.

Accordingly, an object of this invention is to provide an improved starting control system for a free-piston machine, which is especially suitable for use in a plant comprising two or more free-piston machines and a master controller, and which will provide for accidental failure of the machine to start.

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Another object is to provide an internal-combustion-operated air-compressor or gas-generator of the free-piston type with a starting control system adapted automatically to effect the sequence of operations necessary for starting the machine in response to the actuation of a stopping and starting control member, this system having means which are adapted to cause automatic repetition of said sequence of operations and to be rendered inoperative in response to starting of the machine.

As already mentioned, an internal-combustion-operated gas-generator is usually provided with a cushion; this improves the stability of operation. Nevertheless the possible ranges of variation of delivery pressure and quantity of power gas are usually somewhat limited, and another object of this invention is to provide such a gas-generator with improved control means which can be operated automatically or at will to suit its output to the demands of a gas-utilising machine, such as a turbine.

A further object is to provide control means for a group of such gas-generators feeding a common gas-utilising machine, which can be operated automatically or at will to select the number of gas-generators running at any particular time and to vary the outputs of the individual gas-generators so as to adapt the total rate of generation of power gas to the load on the gas-utilising machine while maintaining the highest practicable overall thermal efficiency.

Another object is to provide an internal-combustion-operated gas-generator of the free-piston type with a control member or equivalent means for exerting a control influence (e. g. varying fluid pressure) which, on continued displacement or variation in one sense, is adapted first to reduce the quantity of fuel injected into the power-cylinder per cycle while the overall compression ratio is maintained constant or substantially constant at a maximum value, and thereafter to reduce said compression ratio while the quantity of fuel injected per cycle is maintained at or substantially at its minimum permissible value.

The overall compression ratio depends both on the delivery pressure of the gas-generator, which is substantially equal to the pressure in the power cylinder at the instant when the exhaust ports close, and on the travel of the power piston from the point where the exhaust ports close to the inner dead point of its stroke, and a convenient mode of adjusting the overall compression ratio is to vary the gas-content of the cushion. Accordingly another object of this invention is to provide control means embodying the means for controlling the inner dead point which are described in my patent application Serial No. 492,865, filed June 30, 1943, now U. S. Patent No.

2,470,231, issued May 17, 1949, and which serve to vary automatically the cushion gas-content in dependence on variation of said inner dead point and of the delivery pressure of the gas-generator.

Another object is to provide, in a gas-generator of the kind in which the delivery stroke of the compressor piston coincides with the compression stroke of the power piston, control means capable of varying both the permitted range of variation of the quantity of fuel injected per cycle and also the overall compression ratio in such a manner that a substantially constant outer dead point of the free-piston assembly is attained as the compression ratio is reduced to its minimum value.

Where two or more gas-generators of the free-piston type supply a common gas-utilising machine imposing a varying demand for gas, the starting or stopping of an additional gas-generator of the group tends to produce a substantial change of working pressure owing to the fact that the minimum output of an individual gas-generator substantially exceeds zero. Therefore a further object of this invention is to provide, in control means for a group of internal-combustion-operated gas-generators of the free-piston type, which are intended to supply a common gas-utilising machine adapted to impose a varying demand for gas, a device capable of varying the setting of the control member or members of, or of the means for exerting a control influence on, the gas-generator or gas-generators already or remaining in operation when an additional gas-generator of the group is started or stopped, so as to compensate for the sudden increase or decrease in gas delivery due to that gas-generator.

When only one or two gas-generators of such a group are operating, it may be desirable in certain ranges of load to blow some of the power gas to waste, owing to the fact, hereinbefore referred to, that the minimum output of a gas-generator substantially exceeds zero; and another object of this invention is to provide in the control mechanism of such a group of gas-generators automatic means which are adapted to control a blow-off valve in such a manner that the control characteristics are suited to the number of gas-generators in operation.

Further objects and advantages of the invention will be apparent from the following description of an embodiment of the invention, given by way of example as applied to a group of three gas-generators arranged to feed a turbine through a common manifold, and with reference to the accompanying diagrammatic drawings, in which:

Fig. 1 shows the control system for the fuel-injection pumps of any one of the gas generators,

Fig. 2 shows other parts of the control system for one gas-generator, including means for starting and stopping it,

Fig. 3 is a graph illustrating on a base of time the mode of operation of the mechanism shown in Fig. 2,

Fig. 4 shows the complete installation with the means for controlling all three gas-generators, and

Fig. 5 is a graph illustrating the mode of operation of the installation as a whole.

The three gas-generators, which are denoted by G1, G2 and G3 in Fig. 4, are similar and are adapted to feed gas to a common manifold 130 which supplies a turbine 131. These gas-generators are provided with similar individual control

systems, which are indicated by ICS in Fig. 4 and which form elements of the group control system as a whole. The individual control system will first be described with reference to Figs. 1, 2 and 3.

Each gas-generator, as shown in Fig. 2, which illustrates gas-generator G2 as an example, is of the known opposed-piston type having a power cylinder 10 and two cylinders 11 each of which serves as both a compressor cylinder and a cushion. The inner chambers 12 of the cylinders 11 feed a receiver for scavenging air contained in an engine case 13 and communicating with scavenge ports 14 in the power cylinder 10, and the outer chambers 15 of the cylinders 11 serve as the cushions, for receiving energy from the free-piston assemblies 16 during their out strokes and accelerating them on their in strokes. The free-piston assemblies are connected together by conventional synchronising linkage (not shown). Exhaust ports 17 in the power cylinder communicate with a gas collector 18 connected by a non-return valve 117 and a branch pipe 19 to the gas-delivery manifold 130. The collector 18 is connected to the engine case 13 by a bypass valve 118 adapted to be kept closed by a spring-loaded piston 119 subjected to the collector pressure. The collector is also fitted with a blow-off valve 20 actuated by an oil-pressure relay 21 controlled by a pressure-responsive device 22.

Each of the cushion chambers 15 is adapted to be connected to a starting air chamber 23 by a port controlled by a poppet valve 24. A cylinder 25 having its inner end open to the chamber 23 contains a piston 26 which is rigid with the stem of the valve 24 and which is penetrated by a port provided with a non-return valve 27. A pneumatic servo-motor for maneuvering the free-pistons to their starting positions includes a cylinder 28 containing a spring-loaded piston 29. The rod 30 of this piston passes through the inner end wall of one of the compressor cylinders 12 so as to abut against the piston therein and it also co-operates with a maneuvering interlock valve 31. The cushions 15 are connected by a balance pipe 32 provided with an air release valve 33 normally closed by a spring and adapted to be opened by a pneumatic motor 34.

Referring now to Fig. 1, each gas-generator is provided with two fuel-injection pumps 132 of known type having a rack 133 slidable for varying the quantity of fuel delivered per stroke. The racks are urged by springs 134 towards the position corresponding to zero delivery. The racks are coupled by links 135 to a two-armed lever 136 which is mounted on a fixed bracket 137 and connected by a preloaded spring link 138 to a rack-actuating lever 139 mounted on the bracket 137; the spring link 138 is normally inoperative and it merely allows an emergency trip gear to put the racks to the no-fuel position without disturbing the rest of the mechanism. The trip mechanism includes a strong helical spring 140 normally compressed between a fixed abutment 141 and a collar 142 fast on a rod 143 which is coupled to a crank lever 144 co-operating with one of the racks 133. The spring is normally held by a trigger lever 145 engaging the collar 142 and adapted to be displaced to release the spring, and thus set the fuel-pump racks to the no-fuel position, by any desired trip device 146.

The rack actuating lever 139 is pivoted to a rod 147 which terminates in a roller 148 working between maximum and minimum fuel-pump stop cams 149 and 150. The rod 147 includes a pre-

loaded extension spring link 151 which will enable the minimum stop cam 150 to be manually overridden to stop the machine. The rod 147 can be rocked about its connection with the lever 139, so as to displace the stop roller 148 along the stop cams, by a piston 152 working in a servomotor cylinder 153 in dependence on the delivery pressure P_D of the gas-generator, which is applied to a bellows device 154. This device actuates through a restorer lever 156 a piston valve 155 which controls the flow of oil, admitted from a relay oil pressure source ROP, to the cylinder 153.

When the stop roller 148 is in the position corresponding to minimum gas delivery pressure, it is in contact with both cams, so that, in consequence, there is only one possible fuel-pump setting for running at minimum output. The stop cams are fixed to a carrier plate 157 oscillatable about a horizontal axis 158 coincident with the stop roller 148 when in said lowest pressure position. An adjustment for the idling point serving to vary the fuel-pump setting to compensate for changes in engine friction, for example when starting from cold, may take the form of a hand- or thermostatically-controlled adjustment of the pivot pin of the stop cam carrier plate 157, arranged to allow the outer dead point of the free pistons to be adjusted over a limited range with the stop roller 148 in the idling position. This adjustment, which in the example shown is effected by a lever 159, has a very much reduced effect when the stop roller is at the high-pressure end of the stop cams.

The rack lever 139 is coupled by a link 160 to one end of a two-armed lever 161 pivoted on a fixed bracket 162. A floating lever 163 is disposed more or less parallel to the lever 161, the two levers being linked at said one end by a bar 164 pivoted to the lever 163 and having a pin 165 slidable in a slot 166 in the lever 161 so as to provide a limited degree of lost motion; at the other end the levers 161 and 163 are pivotally connected together by a link 167. The bar 164 is also connected to a main control lever 67, which may be a handle adapted for displacement at will, as well as automatically in a manner which will be hereinafter described. A point 168 on the floating lever 163 corresponding to the pivot of the lever 161 serves as a floating fulcrum which is displaced only when relative motion occurs between the pin 165 and slot 166 of the lost-motion connection between the two levers 161 and 163. The floating fulcrum 168 is connected to the fuel-pump stop cam carrier plate 157 for controlling its position about its fixed pivot 158, by a link 169, a multiplying lever 170, a link 171 and a two-armed lever 172 pivoted on a fixed bracket 173 and having a pin 174 engaged in a fork 175 on the plate 157. The link 171 may have alternative holes 176 for pivotal connection with the lever 172 whereby the compression-ratio range may be varied. The floating fulcrum 168 is also connected, by a rod 177 which is pivotally connected to the link 171, to a device for adjusting the compression ratio at which the gas-generator operates. This device is part of a system for controlling the inner dead point of the free-piston assembly, as described in my said patent application Serial No. 492,865. The portion of the said device shown in the present Fig. 1 includes a bellows device 178 responsive to the pressure P_S existing in the scavenge air receiver 13 of the gas-generator, a follower mechanism 179 responsive to changes in the inner dead point

of the free pistons, and a floating lever 180 for compounding the responses of the elements 178 and 179 and transmitting the resulting by a rod 181 to control means (not shown) for varying the air content of the cushions of the gas-generator, as described in my said patent application. The ratio of the two arms of the floating lever 180 is varied by sliding a bearing pin 182 of a roller 183 along a slot 184 in the lever 180, by the agency of a link 185 connected to the rod 177. The roller 183 co-operates with a crosshead 186 of the dead-centre follower 179 and when it is in the position shown relative to the crosshead the gas-generator operates within its maximum range of compression ratio. As the roller 183 is displaced towards the other end of the crosshead 186, the limits of the compression-ratio range are progressively lowered.

The mode of operation of the individual control system as a whole is as follows. Starting with the main control lever 67 urged towards the position shown corresponding to maximum output, the rack lever 139 is in the position yielding the maximum fuel delivery permitted by the maximum fuel-pump stop cam 149 for the instantaneous gas-generator delivery pressure P_D . If this pressure varies, the servo-motor 152, 153 moves the stop roller 148 along the maximum stop cam 149 which is so shaped as to maintain a predetermined maximum outer dead point of the free-piston assembly. As the main control lever 67 is displaced to reduce the output, the levers 161 and 163 are rocked together, under the action of the fuel-pump rack springs 134, until the stop roller 148 engages the minimum stop cam 150, which is shaped so as to maintain a predetermined minimum outer dead point. So far the compression ratio setting has been maintained at its maximum value, and the stop cam plate 157 has been held stationary. However, on further movement of the main control lever 67 in the same sense, two operations occur simultaneously: firstly, the roller 183 of the inner dead point control system is adjusted so as to cause a continuous reduction in compression ratio; and secondly the fuel-pump stop cam plate 157 is displaced in such a direction as to reduce the fuel delivery to the extent necessary to maintain the outer dead point substantially constant as the compression ratio decreases.

Fig. 2 shows further details of the individual control system, including the starting control mechanism, which comprises an automatic starting repeater valve RV, a starting control valve CV, a maneuvering servo-valve MSV, a starting air valve SAV and a maneuvering air valve MAV. These will be described in turn.

The repeater valve RV has two separate coaxial piston-valve plungers, 35 and 36 associated with springs 37 and 38 which bias them towards their lowest positions. The upper plunger 36 is rigid with a piston 39 working in a cylinder 40, the lower end of which communicates with the engine case 13 through a non-return valve 41 and with the atmosphere by a leak 42. The ports controlled by the upper plunger are so arranged that, when the plunger is at the bottom and the top of its stroke, pipe union 43 and duct 44 are put into communication with each other through ports 45 and 46 respectively, while when this plunger is at an intermediate part of its stroke, the union 43 and the duct 44 are cut off from each other while at the same time the duct 44 is connected to a primary spill port 47. The lower plunger 35 when in its lowest position opens

a series spill port 48 between the spill port 47 and a drainage connection 49, and it closes a port 50 in parallel with the ports 45 and 46. When the lower plunger is in contact with the upper plunger and the latter is stopped at the upper limit of its stroke, the port 48 is closed and the port 50 is open to the duct 44. The union 43 is connected to a pipe 226 (Fig. 4) for conveying a starting oil pressure SOP from a stopping and starting valve which will be hereinafter described.

The starting control valve CV has a plunger 51 biased by a spring 52 towards its left-hand position and provided with a piston 53 working in a cylinder 54, the outer end of which is connected by a pipe 123 to the duct 44 of the starting repeater valve RV and can thus be subjected to starting oil pressure. The valve CV has drain ports 55 and 56, a port 58 connected to the pipe 200 (Fig. 4) that supplies a varying control oil pressure COP to all the gas-generators from the master controller, ports 59 and 60 connected to the source of relay oil pressure ROP which is maintained at a constant pressure and a connection 61 and ports 62 and 63 connected respectively to the two ends of the main control cylinder 64 (shown also in Fig. 1) of the gas-generator and to the starting air valve SAV. A branch pipe 120 connects the port 61 to the pressure-responsive device 22 of the blow-off relay 21.

The maneuvering servo-valve MSV has a plunger 68 biased by a spring 69 towards its right-hand position and adapted to be displaced to the left-hand position by a rod 70 co-operating with the piston 65. A port 71 is connected to the relay oil pressure line ROP; 72 is a drain port, and a connection 73 communicates with the maneuvering air valve MAV.

The starting air valve SAV has a plunger 74 biased downwards by a spring 75 and adapted to be raised by a piston 76 working in a cylinder 77 the lower end of which is connected by a pipe 78 to the relay oil pressure connection 63 of the starting control valve. A spring-biased pneumatically-operated maneuvering safety catch 79 is adapted to prevent the piston 76 from rising more than a short distance above its lowest position, in which the plunger 74 keeps ports 81 and 82 closed, and a similar starting-pressure catch 80 is adapted to prevent the piston 76 from rising above a position such that the plunger puts the ports 81 and 82 into communication with each other. A drain port is denoted by 83. At the upper end of the plunger 74 is a pivoted finger 84 biased by a spring 85 towards a vertical position and provided with a cam surface 86 co-operating with a fixed abutment 87 to rock the finger to the right as the plunger assumes its highest position. A poppet air valve 88 is biased downwards towards its closed position by a spring 89 and is adapted to be raised by the finger 84. Compressed air is supplied by a maneuvering and starting air line AP at constant pressure above the poppet valve 88, and the port 90 of this valve is connected by a duct 91 to the port 81. A pipe 92, including the maneuvering interlock valve 31, branches from the duct 91 and leads to the pneumatic motor of the maneuvering safety catch 79. The port 82 is connected both by a pipe 93 to the outer ends of the starting valve cylinders 25 and also by a pipe 94 to a restriction 95 opening into the lower end of a bore 96 in which the lower plunger 35 of the repeater valve RV operates. The pneumatic motor of the catch 80 is connected by a pipe 122 to the starting air chambers 23.

The maneuvering air valve MAV has a piston

97 working in a cylinder 98 and biased towards its lowest position by a spring 99. The lower end of the cylinder 98 is connected by a pipe 103 to the relay oil pressure connection 73 of the maneuvering servo valve MSV. A rod 100 rigid with the piston 97 carries at its upper end a pivoted finger 101 biased by a spring 102 towards a vertical position. A spring-loaded pneumatically operated trip 104, connected by a pipe 105 to a port 106 in the maneuvering cylinder 28, is adapted to rock the finger 101 to the right. A piston valve 107 has a poppet head 108. When the poppet head 108 is on its seat, connection 109 is closed and the piston valve 107 opens an exhaust port 110. A spring 111 biases the valves 107 and 108 towards their lowest position. Compressed air from the line AP is supplied above the poppet valve 108; its connection 109 communicates through a restriction 112 and a pipe 113 to the right-hand end of the maneuvering cylinder 28, and through a pipe 114 and a restriction 115 to the pneumatic motor of the cushion air release valve 33. The pipe 113 is connected through a restriction 116 to the exhaust port 110.

The mode of operation is as follows. The parts are shown in Fig. 2 in the position corresponding to full load. When the gas-generator is brought to rest and the starting oil pressure SOP drops to atmospheric, cylinder 54 of the starting control valve CV exhausts through duct 44 and port 46 of repeater valve RV, and plunger 51 of valve CV moves to the left; the control oil pressure COP is shut off at port 58, and connection 61 is opened to drain port 55. Consequently pressure-responsive device 22 of blow-off relay 21 is unloaded, this relay holds blow-off valve 20 open and gas-collector 18 is therefore exhausted to atmosphere. Engine case 13 is also exhausted, since by-pass valve 118 opens as the collector pressure falls.

Connection 63 of starting control valve CV is also opened to drain port 56, and plunger 74 of starting air valve SAV therefore drops to its lowest position. The relay oil pressure is applied from line ROP through port 59 and connection 62 of the starting control valve to the right-hand end of control cylinder 64, so that control lever 67 is moved to its stop position. Piston 65 moves plunger 68 of maneuvering servo valve MSV to the left, so that relay oil pressure ROP acts through port 71, connection 73 and pipe 103 to raise piston 97 of maneuvering air valve MAV. Thereupon finger 101 raises valve 107, 108, so that exhaust port 110 is shut and air passes through connection 109 to cushion air release valve cylinder 34 and maneuvering cylinder 28. The release of the engine case pressure has allowed air under pressure in the compressor chambers 12 to escape through the delivery valves, and the pressure in the cushions is released through the cushion air release valve 33 at such a rate that the free-piston assemblies move towards each other; this avoids any risk that the air in the compressor chambers might move these assemblies outwards beyond their correct starting positions.

Maneuvering piston 29 now operates to move the free-piston assemblies outwards to their starting positions, and when piston 29 uncovers port 106, compressed air from maneuvering cylinder 28 passes through pipe 105 and operates trip 104, so that finger 101 is moved to the right, allowing valve 107, 108 to drop and open exhaust port 110. Cushion air release valve 33 accordingly shuts, and maneuvering piston 29 is returned

by its spring to the right-hand position, so that maneuvering safety valve 31 is opened.

The starting operation will be described with reference to Fig. 3, which shows, on a base of time:

Curve I—starting oil pressure on pipe 123.

Curve II—starting air pressure at ports 82 of valve SAV.

Curve III—pressure in engine case 13 if gas-generator fails to start.

Curve IV—pressure in engine case 13 if gas-generator starts.

Curve V—lift of upper plunger 36 of valve RV if gas-generator fails to start.

Curve VA—modification of curve V if gas-generator starts.

Curve VI—lift of lower plunger 35 of valve RV.

Curve VII—opening of either of main supply ports 45 and 46 of valve RV if gas-generator fails to start.

Curve VIIA—modification of curve VII if gas-generator starts.

Curve VIII—opening of primary spill port 47 of valve RV.

Curve IX—opening of parallel supply port 50 of valve RV.

Curve X—opening of series spill port 48 of valve RV.

When the master control operates, in a manner to be hereinafter described, to restart the gas generator at time (a) in Fig. 3, it applies the starting oil pressure SOP to connection 43 of repeater valve RV. When plunger 74 of starting air valve SAV was in its highest position, bore 96 of repeater valve RV was connected through pipe 94 and ports 82 to exhaust port 83, so that lower plunger 35 of valve RV remains in its lowest position. The starting oil pressure is applied through port 45 and duct 44 of valve RV to cylinder 54 of valve CV and moves plunger 51 of the latter to the right.

The control oil pressure COP is applied through port 58 and connection 61 of valve CV, firstly to blow-off relay 21 and causes blow-off valve 20 to be shut, and secondly to the left-hand end of control cylinder 64, so that control lever 67 moves to a running position dependent on the magnitude of the control oil pressure, the right-hand end of this cylinder being vented by the drain port 56. At the same time the relay oil pressure is cut off at port 71 of maneuvering servo valve MSV, since plunger 68 is moved to the right by spring 69, and cylinder 98 of maneuvering air valve MAV is vented by drain port 72, so that piston 97 of valve MAV drops in readiness for the next stopping operation.

In addition, relay oil pressure is applied through port 60 and connection 63 of valve CV to cylinder 77 of starting air valve SAV and raises piston 76 into engagement with catch 79. Thereupon finger 84 opens poppet valve 88 slightly and admits compressed air from line AP through port 90 to duct 91, port 82 still being closed. Air passes from duct 91 through pipe 92, and provided the maneuvering gear is properly set, interlock valve 31 will be open and will pass air to catch 79 which is thus retracted and allows piston 76 to rise into engagement with catch 80. This causes poppet valve 88 to open fully and ports 81 and 82 to be put in communication with each other at time (b) in Fig. 3. Compressed air from line AP thereupon passes through pipe 93 to starting air chambers 23 through non-return valves 27 in starting-valve pistons 26, valves 24 being held closed by the

air pressure; compressed air also passes, at the time (b) in Fig. 3, through pipe 94, to bore 96 of valve RV and raises lower plunger 35 at a limited speed, owing to the restriction 95. After the clearance between plungers 35 and 36 has been taken up, they rise together to the top of their stroke. During this upward stroke, lower plunger 35 first closes series spill port 48, at time (c) in Fig. 3, and immediately thereafter starts to open supply port 50 and picks up upper plunger 36, which begins to close port 45; however the starting oil pressure connection is maintained through valve RV, since as port 45 closes port 50 opens. As soon as upper plunger 36 has closed port 45, at time (d) in Fig. 3, it begins to open primary spill port 47; it then closes spill port 47 again at time (e) and immediately begins to open supply port 46, which is fully open at time (f) when plunger 36 reaches the top of its stroke. Since series spill port 48 is closed before primary spill port 47 opens, there is no loss of starting oil pressure. Both plungers are now in the top position, and valve RV has not interfered in any way with the application of starting oil pressure to valve CV.

When the air pressure in starting air chambers 23 has risen to the correct value, at time (g), this pressure, transmitted by pipe 122, releases catch 80 and allows plunger 74 of valve SAV to rise to the top of its stroke, abutment 87 thereupon rocking finger 84 clear of valve 88 which shuts. Pressure in starting valve cylinders 25 is released to atmosphere through ports 82 and 83, and valve pistons 26 are thrust outwards by the air pressure in starting air vessels 23, opening starting valves 24. The starting air then expands into cushions 15 and drives the free-piston assemblies towards each other. The gas-generator should now start, and, if it does so, the engine case pressure will rise immediately to a value sufficient to hold piston 39 and upper plunger 36 of valve RV at the top of their stroke. Main supply port 46 is therefore open and primary spill port 47 is shut, so that the starting oil pressure is maintained in a cylinder 54 of valve CV. In the meantime, since port 82 of valve SAV has been opened to atmosphere through port 83, lower plunger 35 of valve RV is returned by spring 37 to the bottom of its stroke.

If, on the other hand, the gas-generator fails to start at time (g), there will be no sustained engine case pressure, and upper plunger 36 of valve RV will drop under the force of spring 38 at a low speed determined by leak 42. Lower plunger 35, however, drops comparatively rapidly and reaches the bottom of its stroke at time (h), closing parallel supply port 50 and opening series spill port 48. Thereafter upper plunger 36, in its downward travel, closes main supply port 46 at time (i) and then opens primary spill port 47, thereby releasing the starting oil pressure from cylinder 54 of valve CV, plunger 51 of which accordingly returns to its left-hand position ready for another attempt to start.

Top plunger 36 of valve RV falls slowly enough for the maneuvering process to be completed in the manner hereinbefore described, and thereafter, at time (j), it closes primary spill port 47 and reopens main supply port 45. Thereupon plunger 51 of valve CV is again moved to the right, and the starting operation is repeated, exactly as at the first attempt, except that lower plunger 35 of valve RV begins to rise before upper plunger 36 has reached the bottom of its stroke; but this has no effect on the operation,

as upper plunger 36 is met at time (m) by lower plunger 35 and lifted as before.

The master control gear, shown in Fig. 4, is arranged to actuate in unison the main control levers 67 of the three gas-generators in response to displacement of a master control lever, which may be hand operated, but which in the present example is actuated by a governor 187 of the turbine 131. The master control gear also starts and stops individual gas-generators as is necessary to accommodate the plant to a varying load.

As already mentioned, each of the gas-generators is provided with an individual gas-collector chamber 18 connected to the common gas manifold 130 by a gas-outlet valve 117 which is in effect, a non-return valve, but which is conveniently operated by an oil servo-motor controlled by a differential device responsive to collector pressure and manifold pressure. The servo-motor consists of a piston 188 working in a cylinder 189; a piston valve 190, which controls the supply of oil from the relay oil pressure source ROP to either end of the cylinder 189, is actuated by a piston 191 working in a cylinder 192 and loaded by a spring 193. Gas-collector pressure is applied to one end of the cylinder 192 through a pipe 194 and acts on the piston in opposition to the spring, while manifold pressure is applied to the other end of the cylinder through a pipe 195. When the gas-collector pressure falls to manifold pressure, the spring 193 ensures that the valve 117 is kept shut; when the gas collector pressure exceeds the manifold pressure sufficiently to displace the piston 191 against the spring force, the valve 117 opens.

The control oil pressure COP applied to pipe 200 is determined by a mechanism consisting basically of an automatic control oil pressure regulator composed of a bellows responsive to control oil pressure, a valve for varying the control oil pressure and a restorer lever. The setting of this regulator is determined by the position of the input point of the restorer lever, and this setting is controlled by a bellows responsive to delivery pressure P_d . This combination constitutes a regulator for the delivery pressure, the setting of which can be adjusted by means of a master control lever. The said valve is a balanced piston-type valve 199 adapted to connect the control oil pressure main 200 alternatively to a source of oil at constant pressure, e. g. the relay oil pressure source ROP, and to exhaust. The valve 199 is actuated by a differential lever 201 connected to a bellows device 202 responsive to control oil pressure and to a second differential lever 203 which is connected to a variable-datum device 198 through a lever 204 and to a third differential lever 205, the lever 205 being connected to the working pressure bellows 197 and to the master control lever 196. The arrangement is such that, if the delivery pressure P_d in the manifold 130 falls, the valve 199 is displaced to the right so as to increase the control oil pressure and thereby cause the individual main control levers 67 of the gas-generators to be moved so as to increase the rate of fuel supply. The master control lever 196 has the effect of altering the setting of the working pressure bellows 197.

The working pressure bellows is of the spring-loaded type, housed in a gas-tight casing communicating with the manifold by a pipe 206. In order to secure at the same time high sensitivity and stability of operation of the master control gear, the duct connecting this casing to the manifold may be controlled by a needle valve 207

actuated by the bellows. This needle valve is so arranged as to decrease the degree of throttling with increasing working pressure at least over the middle and lower part of the working pressure range.

The object of the variable-datum device 198 is to assist the working pressure bellows 197 to maintain a constant delivery pressure when a gas-generator is started or stopped, and for this purpose it is arranged to be responsive to the starting and stopping of the delivery of gas from the gas-generator to the common manifold. The preferred arrangement shown employs the response of the gas-outlet valves 117. Accordingly the device 198 is provided with two cylinders 208 and 209 connected respectively by pipes 210 and 211 with the servo-motor cylinder 189 of the gas-generators G2 and G3 in such a manner that the relay oil pressure, when it is applied to either of these cylinders 189 to open the gas delivery valve 117, also energises the cylinder 208 or 209 communicating therewith. The device 198 also includes a slidable bar 212 pivotally connected to the lever 204 and urged to the right by a compression spring 213. A crosshead 214 fast on the bar 212 co-operates with a short plunger 215 and a long plunger 216 having limited degrees of sliding movement respectively in the cylinders 208 and 209. The bar 212 and lever 204 can thus assume three predetermined positions: first, that shown when both cylinders 208 and 209 are energised and the long plunger 216 controls the position of the crosshead; second, an intermediate position where only the cylinder 208 is energised and the short plunger 215 locates the crosshead; and third, the extreme right-hand position where both cylinders 208 and 209 are de-energised and the crosshead is held against a stop 217 by the spring 213. The variable-datum device thus operates to move the fulcrum of the differential lever 203 by a distance appropriate to correct the control oil pressure and hence the setting of the main control levers 67. Thus, when an additional gas-generator, for example, starts, the fuel supply of all the gas-generators operating is abruptly reduced so as to compensate for the additional source of power gas, without any change in the setting of the master control lever 196 or any motion of the working pressure bellows 197 other than that due to a relatively slight final correction.

The gas-generator G1 is the first to be started and the last to be stopped, while the gas-generator G2 is the next to be started as the load rises and is stopped next before G1 as the load falls. The servo-motor 21 controlling the blow-off valve 20 of gas-generator G2, as already described with reference to Fig. 2, is controlled by the bellows device 22 which is adapted to be energized by the control oil pressure applied through the pipe 120. The servo-motor includes a piston 218 coupled through a crank lever 219 to the valve 20 and operating in a cylinder 230 to the ends of which oil from the relay oil pressure source is admitted alternatively by a valve 220 controlled by a restorer lever 221 coupled to the bellows device 22 and deriving a return motion from the piston 218. The servo-motor 21 of the gas-generator G3 is similar to that of the gas-generator G2. The servo-motor 21A controlling the blow-off valve of the gas-generator G1 is again similar to the servo-motors 21 with the exception that its restorer lever 221 is controlled by two oil pressure responsive bellows 22 and 22 acting in opposition. The bellows 22 are energized by relay oil pressure controlled by the

individual control system ICS of the gas-generator G1, while the bellows 222, which have a smaller effective area than the bellows 22, are subjected to the control oil pressure in the individual control system of the gas-generator G2, this pressure being taken off the pipe 120 of gas-generator G2 by a branch 223.

The master control lever controls three starting-and-stopping valves which respectively control the three starting oil pressure circuits of the three gas-generators. These valves are shown diagrammatically as combined in a rotary distributing valve 224 connected to the shaft of the master control lever 196 by a driving coupling providing a small degree of lost motion, indicated at 229. This provides a margin for increase of load, after a gas-generator has been stopped, before it is required to be started again. In the position shown, the valve 224 puts the source of relay oil pressure ROP into communication with three pipes 225, 226 and 227 which connect to the starting oil pressure ports 43 (Fig. 2) of the repeater valves RV of the three gas generators G1, G2 and G3 respectively. As the master control lever 196 is displaced in a counter-clockwise direction, the pipes 227, 226 and 225 are successively and in this order disconnected from the source ROP and put into communication with a drain port 228.

The mode of operation of this plant will be described with reference to Fig. 5, which represents the characteristic of each gas-generator by a family of curves on a graph having heat in fuel per cycle (which corresponds to displacement of the fuel-pump racks 133 in Fig. 1) as ordinate (left-hand scale) and absolute delivery pressure P_d of the gas as abscissa. For convenience of description, the rack displacement will be referred to as a percentage of full-load displacement from the zero delivery position at the origin, and the gas pressure will be assumed to rise to 71 lb./sq. in. abs. at full load. The uppermost curve I of the family corresponds to an overall compression ratio of 16:1 and maximum outer dead point. The fuel-pump stop cams 149 and 150 (Fig. 1), as already explained, are shaped to give only one possible setting at idling, and consequently the lower end of curve I droops slightly to a common point Q at 27% fuel and atmospheric pressure. Curves II, III and IV correspond respectively to overall compression-ratio settings of 16:1, 12:1, and 10:1 respectively and to minimum outer dead point. The lower end of curve IV below about 21 lb./sq. in. pressure drops less steeply to the common point Q. Curve V shows the turbine power characteristic, the percentage power output being given by the shorter right-hand ordinate scale.

The operations involved in varying the load from full to stop and back again to full will now be described. Starting at full load with all three gas-generators running, initial displacement of the master control lever 196 from the position in which it appears in Fig. 4 reduces the working pressure from 71 to 47.5 lb./sq. in. along chain-dotted track ABCE, the turbine output dropping to 43%.

The longer right-hand ordinate scale represents control oil pressure COP of the master control gear as a percentage of the maximum value, and for convenience of description this scale has been so chosen that the track AB represents both rack position and control oil pressure. When the compression ratio setting is changed, for example over the range BE, the main control lever 67 of each gas-generator has to change not only the

fuel-pump setting, but also the compression ratio setting, so that the dotted line BE' representing the control oil pressure over this range is steeper than the line BE.

In order to reduce the load further, gas-generator G3 must be stopped, and this is done by the stopping and starting valve 224 which is actuated by the master control lever 196 as it moves into the position corresponding to the delivery pressure of 47.5 lb./sq. in. to connect pipe 227 to the drain 228. As a result, the main control lever 67 of gas-generator G3 is moved by its main control piston 65 into the stop position, and the individual control system operates, as hereinbefore described with reference to Fig. 2, to maneuver the free pistons of this gas-generator into their starting position. Gas-generators G1 and G2 must now carry the load, and the variable-datum device 198 operates, as delivery of gas by gas-generator G3 ceases and causes the cylinder 209 of the variable-datum device to be de-energised, to set them at point F, i. e. in the range of constant maximum compression ratio setting. The load is still further reduced, and, when the pressure denoted by points H and H' is reached, along the tracks FGH for fuel-pump rack setting and FGH' for control oil pressure, the compression ratio being now at its minimum working value, the blow-off valves 20 of gas-generators G1 and G2 begin to open under the influence of their blow-off relays 21A and 21. As the control oil pressure drops from H' to K' and the delivery pressure from H to K along curve IV, each blow-off valve opens gradually wider under the influence of the falling control oil pressure, the rates and initial loadings of the bellows springs being so selected that the two blow-off valves operate similarly. During this time the compression-ratio setting remains at the minimum of 10:1, as determined by the lost motion between the pin 165 and the slot 166 (Fig. 1). The fuel-pump rack setting is also that determined by the minimum fuel-pump stop cam 150, but as the delivery pressure falls, this cam recedes, allowing the rack setting to be further reduced.

To reduce the load below 26 lb./sq. in., gas-generator G2 is stopped by means of the stopping-and-starting valve 224 which connects pipe 226 to the drain 228, and the variable-datum device 198 thereupon operates, on de-energising of its cylinder 208, to step up the control oil pressure from K' to L. As the load is still further reduced, blowing-off must start again at the points N, N', when the control oil pressure has dropped to 46%, which is much lower than at the point H'; for this reason the setting of the blow-off relay 21A has been altered by putting out of action the smaller bellows 222 owing to its connection to the control oil pressure applied through the individual control system of the gas-generator G2. When the minimum delivery pressure is reached with the blow-off valve 20 wide open, final movement of the master control lever 196 actuates the stopping-and-starting valve to stop gas-generator G1 by connecting its pipe 227 to drain.

The process of starting the gas-generators and bringing them successively on load is largely a reversal of the above described sequence, but there are some aspects that will be further discussed.

The procedure in changing from stop to full load is then briefly as follows.

When gas-generator G1 is started by movement of the master control lever 196 from the stop position, the blow-off valve 20 of this gas-generator will be open because the control oil pressure is

very low unless the master control lever has been moved too far. With the blow-off fully open there will be an excess pressure in the gas collector 18 of about 1.5 lb./sq. in., so that the gas outlet valve 117 will open and some gas will pass to the turbine. If the master control lever is moved slowly so that the gas pressure is kept to its equilibrium value, then the track followed on Fig. 5 will be the reverse of that described when stopping, i. e. QQ', NN', M, L, but from there it will go to J before gas-generator G2 is started, owing to the backlash, indicated at 229 in Fig. 4, provided between the valve 224 and the lever 196.

On the other hand, if this lever is moved immediately up to the position corresponding to steady running at the point J, the control oil pressure rises to a high value because the gas pressure is temporarily lower than that corresponding to this position. Therefore the blow-off valve closes rapidly, instead of remaining open over the range QN, and also the high control oil pressure will push the main control lever 67 of gas-generator G1 over to the top limit, i. e., putting the compression ratio setting at maximum (16:1) and the stop roller 148 against the maximum fuel cam 149, giving the maximum outer dead point. Thus in this case the track will go from Q along the upper limit curve to J, the control oil pressure being indeterminate but high, approximately equal to the full relay oil pressure to start with, and falling of course to the equilibrium value at J.

Proceeding slowly upwards from point J by moving the master control lever 196 a very small amount, the stopping and starting valve 224 operates to start gas-generator G2, and the degree of opening of its blow-off valve 20 is gradually reduced, raising the pressure in its gas collector 18 to the manifold pressure, namely 26.5 lb./sq. in. During this time the control oil pressure will be at J (19), so that the compression ratio setting and fuel will be at maximum, and the track of gas-generator G2 will be along the upper limit curve I of Fig. 5 from Q to J with the whole output from gas-generator G2 blowing off.

As the blow-off valve of gas-generator G2 closes further, the gas-outlet valve 117 of this gas-generator opens, and gas in increasing quantity is delivered to the manifold. The master control in its role of gas-pressure controller, in order to keep the delivery pressure constant, reduces the control oil pressure, thereby opening the blow-off valve on gas-generator G1, and this therefore follows the vertical track from J to P. Both gas-generators G1 and G2 are now working at the point PP' with a control oil pressure of about 45%. Proceeding upwards slowly, both gas-generators follow the track PP', HH', G, F, and then on to point D.

If, on the other hand, the master control is moved immediately from point J to a position corresponding to point D, the control oil pressure will be high, approximately at full relay oil pressure, so that, as soon as gas-generator G2 starts to deliver gas, both gas-generators follow the top limit curve I from J to D, i. e. gas-generator G1 does not blow-off at all, and point D is reached when the blow-off valve of gas-generator G2 has closed fully.

The process of starting up gas-generator G3 and bringing the set on to full load at point A is exactly similar to that described above, except that as G3 comes in, G1 and G2 do not blow off as the point C is well above the lower limit curve IV.

The variable-datum device 198 should ideally

have a time constant equal to that of the control or operation which it is required to compensate. Consequently the characteristics of the return spring or springs and the flow-capacities of the connections to the cylinders 208 and 209 are so chosen as to give time constants which will avoid or reduce temporary errors in speed or delivery pressure.

I claim:

1. An internal-combustion-operated free-piston machine having a free-piston assembly, starting mechanism including means for maneuvering said assembly to a starting position adjacent to one limit of its stroke, means for accelerating said assembly from said position towards the other limit of its stroke, and a starting control member operable to cause at least both said means to operate in the sequence necessary to start the machine, repeater means operatively associated with said starting mechanism for causing automatic repetition of said sequence, and means responsive to starting of the machine for rendering said repeater means inoperative.

2. An internal-combustion-operated free-piston machine having a free-piston assembly and including automatic starting means serving to effect, in response to release therefrom and application thereto of a starting fluid pressure, a sequence of operations which are necessary to start the machine and which include maneuvering said assembly to a starting position adjacent to one limit of its stroke and accelerating the assembly from said position towards the other limit of its stroke, a control valve operable for applying and releasing said pressure to and from said means, repeater means serving to cause automatic repetition of said sequence of operations, said repeater means including a repeater valve which in one condition connects said control valve to said automatic starting means, which in a second condition releases said pressure from said automatic starting means, and which is so biased that it tends to assume said second condition in response to application of said pressure to said automatic starting means and after a predetermined time lag to revert to said one condition, and means responsive to starting of the machine for maintaining said repeater valve in said one condition.

3. An internal-combustion-operated free-piston machine having a free-piston assembly including a pump piston, a receiver arranged to be charged by said pump piston, a starting control member operable to cause at least both said means to operate in the sequence necessary to start the machine, repeater means operatively associated with said starting mechanism for causing automatic repetition of said sequence, and means responsive to increase of pressure in said receiver for disabling said repeater means.

4. An internal-combustion-operated free-piston machine including automatic starting means capable, in response to release therefrom and subsequent application thereto of a starting fluid pressure, of effecting a sequence of operations which are necessary to start the machine and which include maneuvering said assembly to a starting position adjacent to one limit of its stroke and accelerating the assembly from said position towards the other limit of its stroke, a control valve operable for applying and releasing said pressure to and from said means, a starting repeater valve connected between said control valve and said automatic starting means, said

repeater valve including a first closure member which is biased to one end position, which puts said control valve in communication with said starting means when in both end positions, and which prepares to release said pressure from said starting means when in an intermediate position, means for overcoming the bias on said closure member in response to starting of said machine, and a second closure member which is biased to one end position in which it co-operates with said first closure member to release said pressure from said starting means, which puts said control valve in communication with said starting means when displaced from said one end position, and which is capable on such displacement of shifting said first closure member against its bias, and means responsive to application of said pressure to said starting means for displacing said second closure member to its other end position and thereafter permitting it to return to its first end position.

5. An internal-combustion-operated free-piston machine including automatic starting means capable, in response to release therefrom and subsequent application thereto of a starting fluid pressure, of effecting a sequence of operations which are necessary to start the machine and which include maneuvering said assembly to a starting position adjacent to one limit of its stroke and accelerating the assembly from said position towards the other limit of its stroke, a control valve operable for applying and releasing said pressure to and from said means, a starting repeater valve connected between said control valve and said automatic starting means, said repeater valve having two relatively movable closure members each associated with a fluid pressure motor and co-operating, firstly on energizing of one of said motors, to maintain said control valve in communication with said starting means, secondly, on subsequent energizing of the other of said motors and de-energizing of said one motor also to maintain such communication, and alternatively, on de-energizing of said one motor without energizing of said other motor, of releasing said pressure from said starting means, means for energizing and subsequently de-energizing said one motor in response to application of said pressure to said starting means, and means for energizing said other motor in response to starting of said machine.

6. An internal-combustion-operated gas-generator of the free-piston type including a power cylinder, a free-piston assembly cooperating with said cylinder, means for injecting fuel into said cylinder, a fuel-control member operable for varying the quantity of fuel injected per cycle, a compression-ratio control member operable for varying the overall compression ratio of the working fluid in said power cylinder, and main control means operatively associated with said control members in such a manner that on continued variation of said main control means in one sense first the fuel-quantity is reduced while said compression-ratio is maintained substantially constant at a maximum value and thereafter said compression-ratio is reduced while the fuel-quantity is maintained substantially at its minimum permissible value.

7. An internal-combustion-operated gas-generator of the free-piston type including a power cylinder, a free-piston assembly cooperating with said cylinder, means for injecting fuel into said cylinder, a fuel-control member operable for

varying the quantity of fuel injected per cycle and biased towards the position yielding minimum fuel-delivery, a compression-ratio control member operable for varying the overall compression ratio of the working fluid in said power cylinder, a common control member, an operative connection including a lost-motion device between said common control member and said fuel-control member, and means responsive to relative displacement of the elements of said lost-motion device for actuating said compression-ratio control member in such a sense as to reduce the compression-ratio as said common control member approaches the end of its range of travel yielding minimum output.

8. An internal-combustion-operated gas-generator of the free-piston type including a power cylinder, a free-piston assembly cooperating with said cylinder, means for injecting fuel into said cylinder, a fuel-control member operable for varying the quantity of fuel injected per cycle, a compression-ratio control member operable for varying the overall compression ratio of the working fluid in said power cylinder, a common control member, an operative connection between said common control member and said fuel-control member arranged to give a ratio of velocity of displacement of said common control member to that of said fuel-control member, which is higher over the lower part of the power-output range than over the higher part thereof, and a connection operative between said common control member and said compression-ratio control member substantially only over said lower part of the power-output range.

9. A free-piston internal-combustion-operated gas-generator having a compressor cylinder, a power cylinder, a free-piston assembly of a compressor piston and a power piston co-operating with said cylinders respectively, the gas-generator being of the kind in which the delivery stroke of its compressor piston coincides with the compression stroke of its power piston and including a fuel-control member operable for varying the quantity of fuel injected into its power cylinder per cycle, a compression-ratio control member operable for varying the overall compression ratio of the working fluid in the power cylinder, and an adjustable device which serves for varying the permitted range of displacement of said fuel-control member, said device being so interconnected with said compression-ratio control member that as the compression ratio is reduced to its minimum value while said fuel-control member is maintained at the lower limit of the varying range permitted by said device, the outer dead point of the free-piston assembly of the gas-generator remains substantially constant.

10. A free-piston internal-combustion-operated gas-generator having a power cylinder, a compressor cylinder, a free-piston assembly co-operating with said cylinders in such a manner that the delivery stroke of the compressor piston coincides with the compression stroke of the power piston, means for injecting fuel into said power cylinder, a fuel-control member for varying the fuel-quantity injected per cycle, a compression-ratio control member for varying the overall compression ratio of working fluid in said power cylinder, an adjustable device capable of varying the permitted range of displacement of said fuel-control member, means responsive to variation in the gas-delivery pressure of the gas-generator for adjusting said device so as to vary at least the magnitude of said range, and an op-

erative connection between said compression-ratio control member and said adjustable device for varying the absolute value of the lower limit of said range in such a manner as to reduce variation in the outer dead point of said free-piston assembly consequent on displacement of said compression-ratio control member.

11. A free-piston internal-combustion-operated gas-generator having a power cylinder, a compressor cylinder, a free-piston assembly co-operating with said cylinders in such a manner that the delivery stroke of the compressor piston coincides with the compression stroke of the power piston, means for injecting fuel into said power cylinder, a fuel-control member for varying the fuel-quantity injected per cycle, a compression-ratio control member for varying the overall compression ratio of working fluid in said power cylinder, an adjustable device capable of varying the permitted range of displacement of said fuel-control member, means responsive to variation in the gas-delivery pressure of the gas-generator for adjusting said device so as to vary at least the magnitude of said range, a common control member, means biasing said fuel-control member towards the position yielding minimum fuel-quantity, an operative connection including a lost-motion coupling between said common control member and said fuel-control member, means responsive to relative displacement of the elements of said lost-motion coupling for actuating said compression-ratio control member in such a sense as to reduce the compression ratio as said common control member approaches the end of its range of travel yielding minimum output, and an operative connection between said compression-ratio control member and said adjustable device for varying the absolute value of the lower limit of said range in such a manner as substantially to eliminate variation in the outer dead point of said free-piston assembly consequent on displacement of said compression-ratio control member.

12. A free-piston internal-combustion-operated gas-generator having a power cylinder, a compressor cylinder, a free-piston assembly co-operating with said cylinders in such a manner that the delivery stroke of the compressor piston coincides with the compression stroke of the power piston, means for injecting fuel into said power cylinder, a fuel-control member for varying the fuel-quantity injected per cycle, a compression-ratio control member for varying the overall compression ratio of working fluid in said power cylinder, maximum and minimum fuel-quantity cams, a cam-follower co-operating with said cams and connected to said fuel-control member for limiting displacement thereof, means responsive to gas delivery pressure for displacing said cam-follower relatively to said cams in a sense such as to vary both the range and the absolute value of the limits of displacement of the fuel-control member, means responsive to displacement of said compression-ratio control member for displacing said minimum fuel-quantity cam relatively to said cam-follower in such a sense as to reduce the minimum fuel-quantity as the compression ratio is lowered, means biasing said fuel-control member towards its position yielding minimum fuel delivery, a common control member, a lost-motion coupling between said common control member and said fuel-control member, and means responsive to lost motion in said coupling for actuating said compression-ratio control member in such a

sense as to lower the compression ratio as said common control member approaches the position corresponding to minimum power output.

13. A group of internal-combustion-operated gas-generators of the free-piston type connected to supply a common gas-utilising machine adapted to impose a varying demand for gas, each of said gas-generators having an individual control system including a main control member and operable for varying its power output in response to displacement of said main control member, and said group having a master control system including means for actuating said main control members, a variable-datum device capable of varying the setting of said means so as to vary the output of those of said gas-generators already in or remaining in operation when an additional gas-generator of said group is started or stopped respectively, and means responsive to the delivery of gas by said additional gas-generator for automatically adjusting the setting of said variable-datum device so as at least in part to compensate for the tendency of the gas-delivery pressure to change as a result of such starting and stopping.

14. A group of internal-combustion-operated gas-generators of the free-piston type connected to supply a common gas-utilising machine adapted to impose a varying demand for gas, each of said gas-generators having an individual control system including a main control member and operable for varying its power output in response to displacement of said main control member, and said group having a master control system including means for actuating said main control members, a variable-datum device capable of varying the setting of said means so as to vary the output of those of said gas-generators already in or remaining in operation when an additional gas-generator of said group is started or stopped respectively, an automatically opening delivery valve between at least one of said gas-generators and said common machine, and means responsive to opening of said valve for automatically adjusting the setting of said variable-datum device so as at least in part to compensate for the tendency of the gas-delivery pressure to change as a result of such starting and stopping.

15. A group of internal-combustion-operated gas-generators of the free-piston type connected to supply a common gas-utilising machine adapted to impose a varying demand for gas, each of said gas-generators having an individual control system operable for varying its power output in response to variation of a control fluid pressure, and said group having a master control system including a control fluid pressure main, a master control member, a device responsive to said control fluid pressure, a device responsive to the delivery pressure of the gas supplied to said machine, a variable-datum device and a two-way valve for connecting said control fluid pressure main alternatively to a source of fluid at super-atmospheric pressure and to a reservoir for fluid at a pressure lower than that of said source, said master control member, said three devices and said valve being differentially connected together, and means responsive to the starting or stopping of at least one gas-generator of said group for automatically adjusting the setting of said variable-datum device so as at least partly to compensate for the tendency of the gas delivery of the group to increase or decrease suddenly when said one gas-generator is started or stopped.

16. A group of internal-combustion-operated

gas-generators of the free-piston type connected to supply a common gas-utilising machine adapted to impose a varying demand for gas, each of said gas-generators having an individual control system operable for varying its power output in response to variation of a control fluid pressure, an automatically opening delivery valve between at least one of said gas-generators and said common machine, said group having a master control system including a control fluid pressure main, a master control member, a device responsive to said control fluid pressure, a device responsive to the delivery pressure of the gas supplied to said machine, a variable-datum device and a two-way valve for connecting said control fluid pressure main alternatively to a source of fluid at superatmospheric pressure and to a reservoir for fluid at a pressure lower than that of said source, said master control member, said three devices and said valve being differentially connected together, and means responsive to the operation of said delivery valve for automatically adjusting the setting of said variable-datum device so as at least partly to compensate for the tendency of the gas-delivery of the group to increase and decrease suddenly when said one gas-generator is started and stopped.

17. A group of internal-combustion-operated gas-generators of the free-piston type connected to supply a common gas-utilising machine adapted to impose a varying demand for gas, each of said gas-generators having an individual control system including a main control member and operable for varying its power output in response to displacement of said main control member, a valve for blowing-off gas, and automatic means responsive to displacement of said main control member for controlling said blow-off valve, said group having a master control system including means for actuating said main control members and for starting and stopping individual gas-generators of said group, and means responsive to alteration in the number of said gas-generators in operation for varying the control characteristic of said automatic blow-off control means.

18. A group of internal-combustion-operated gas-generators of the free-piston type connected to supply a common gas-utilising machine adapted to impose a varying demand for gas, each of said gas-generators having an individual control system operable for varying its power output in response to variation of a control fluid pressure, and at least one of said gas-generators having a blow-off valve branched from a supply conduit leading to said gas-utilising machine, and said group having a master control system including means for varying said control fluid pressure to suit the load on said machine, means for starting and stopping individual gas-generators of said group, and two differentially-acting devices responsive to variation in said control fluid pressure for automatically and progressively operating said blow-off valve, said starting and stopping means serving to de-energise one of said fluid-pressure-responsive devices on stopping of another gas-generator of said group.

19. A group of internal-combustion-operated gas-generators of the free-piston type connected to supply a common gas-utilising machine adapted to impose a varying demand for gas, each of said gas-generators having an individual con-

trol system operable for varying its power output in response to variation of a control fluid pressure and for starting and stopping it in response to application to and release from said system of a starting fluid pressure, and said group having a master control system including a differential mechanism associated with a master control member, with a device responsive to the pressure of the gas supplied to said machine, with a variable-datum device and with a fluid control valve for varying said control fluid pressure, valve means operatively connected with said master control member for supplying said starting fluid pressure to said individual control systems in succession as said master control member is progressively advanced towards the full-load position, and means responsive to the delivery of gas by one of said group for varying the setting of said variable-datum device so as to adjust said control fluid pressure to compensate for such delivery.

20. A gas-generator of the two-stroke compression-ignition free-piston type including a power cylinder having piston-controlled scavenge ports and exhaust ports, a compressor cylinder co-axial with said power cylinder, a free-piston assembly including a power piston working in said power cylinder and a compressor piston working in said compressor cylinder, a scavenge air receiver communicating with said scavenge ports, a delivery valve communicating between said receiver and the end of said compressor cylinder nearer to said power cylinder, an inlet valve opening into the said end, the other end of said compressor cylinder forming a cushion, a fluid-pressure-actuated valve for exhausting said cushion, a fluid pressure motor for maneuvering said free-piston assembly to a starting position, means for admitting a charge of starting gas into said cushion, a fluid-pressure-actuated valve for exhausting said receiver, and automatic control means serving when the gas-generator is stopped to open said last-mentioned valve and thereby permit said free-piston assembly to assume under the influence of the cushion pressure a position on the inner side of its starting position, to release the cushion pressure through said cushion-exhaust valve and to energise said motor and thus cause it to move said free-piston assembly out to its starting position.

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