Sept. 24, 1946. F. A. I. MUNTZ 2,408,089

INTERNAL-COMBUSTION ENGINE

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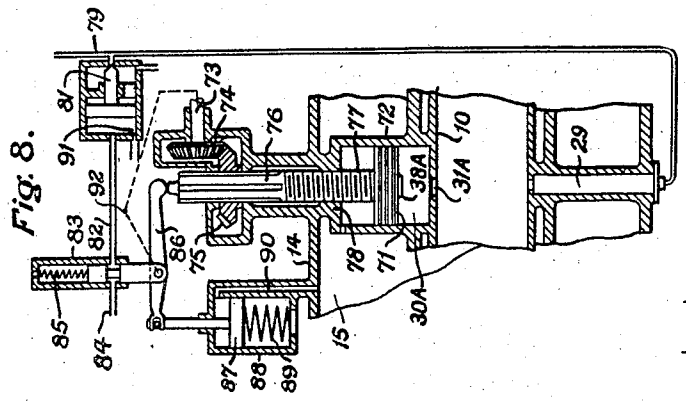


Fig. 8.

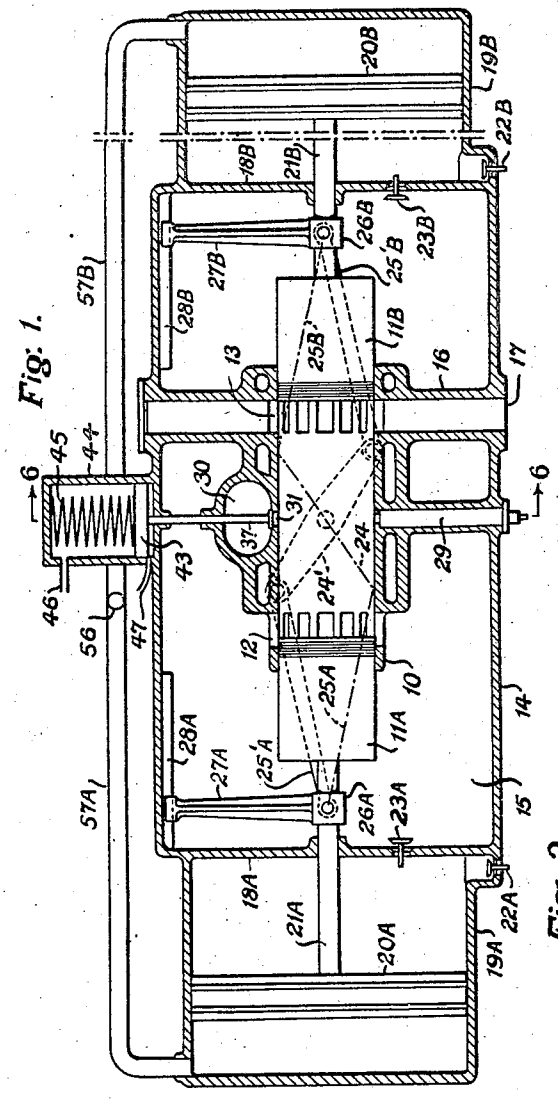


Fig. 1.

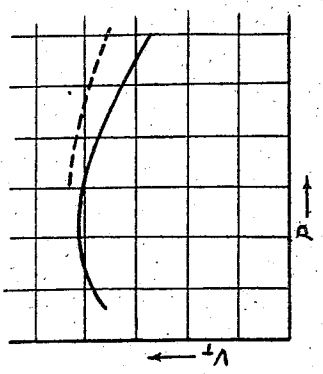


Fig. 4.

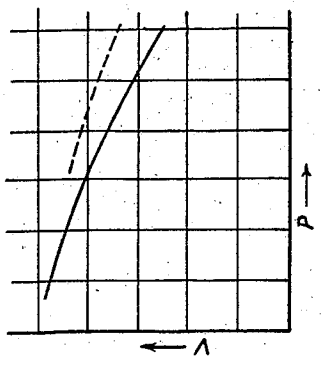


Fig. 3.

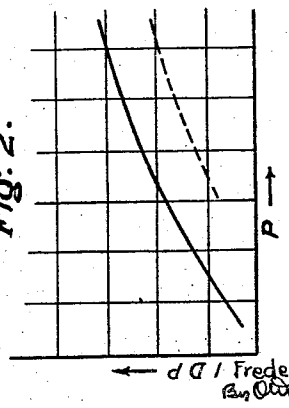


Fig. 2.

INVENTOR
Muntz
Frederick Alan Irving
By Otis Mills his ATT'Y

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INTERNAL-COMBUSTION ENGINE

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Fig. 6.

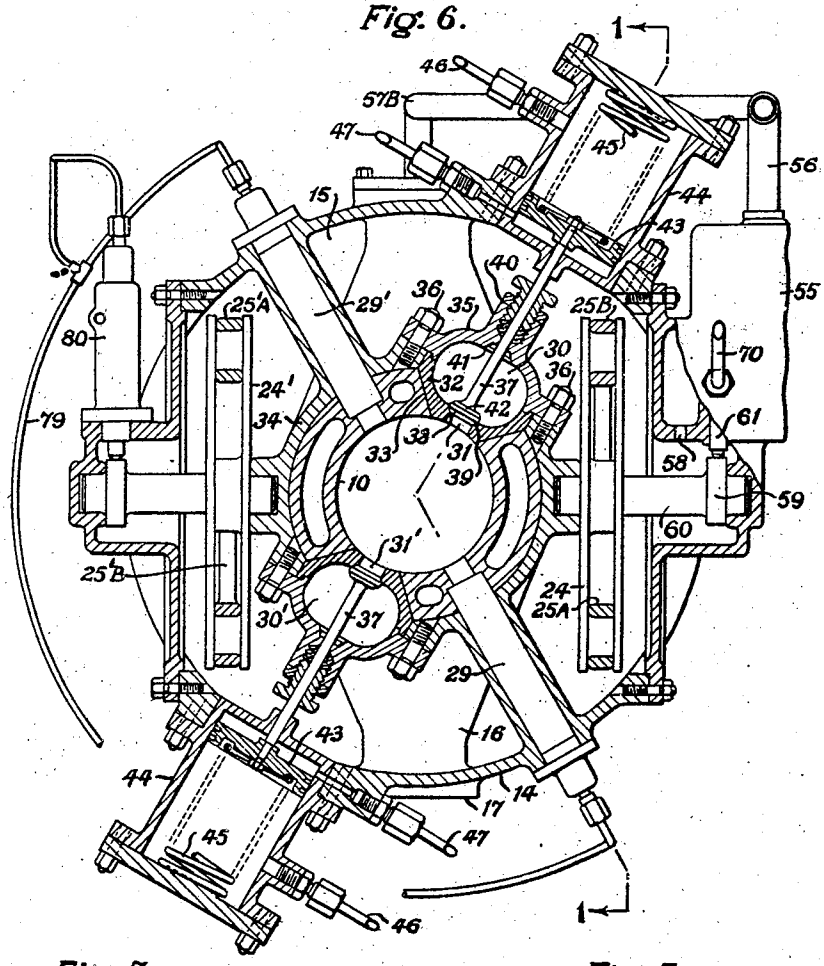


Fig. 7.

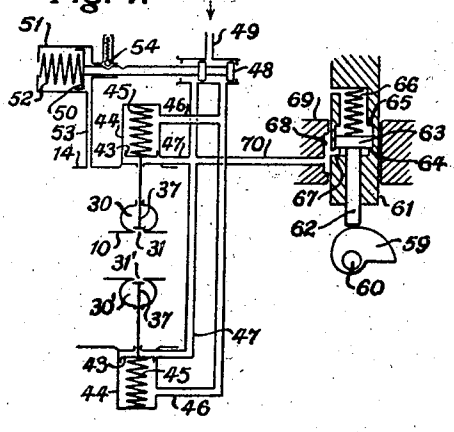
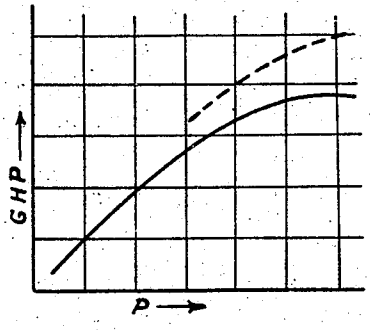


Fig. 5.



INVENTOR
Frederick Alan Irving MUNTZ
By
his ATT'Y.

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Fig. 10.

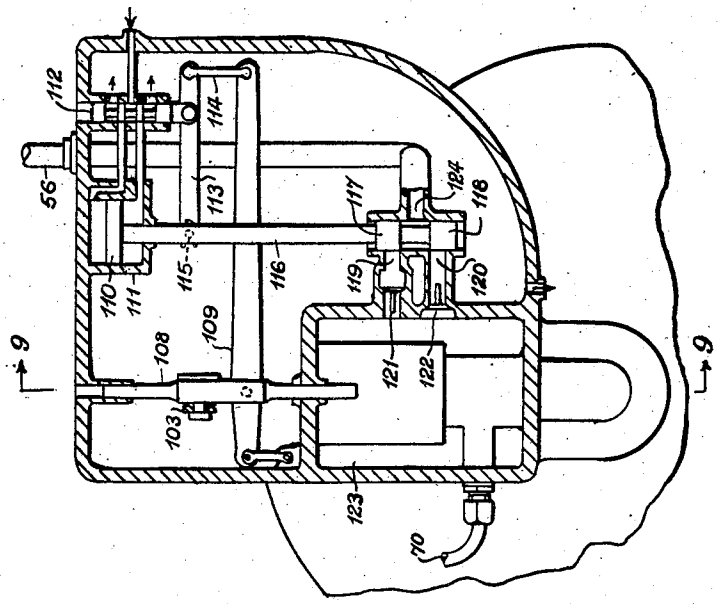
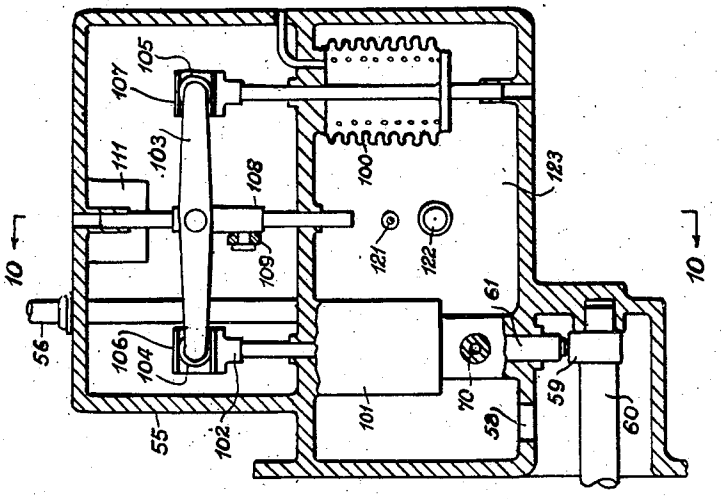


Fig. 9.



Inventor
Frederick A I Muntz
by
Blair W Tunbank
his attorney

Patented Sept. 24, 1946 2,408,089

UNITED STATES PATENT OFFICE

2,408,089

INTERNAL-COMBUSTION ENGINE

Frederick Alan Irving Muntz, Hounslow, England, assignor to Alan Muntz & Company Limited, Hounslow, England, a company of Great Britain

Application February 27, 1943, Serial No. 477,395
In Great Britain February 12, 1942

13 Claims. (Cl. 123—46)

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This invention relates to internal-combustion-operated reciprocating machines of the kind in which a power piston and a compressor piston are connected together for operation in unison, the movement of this piston assembly being so controlled that the inner dead point of the power piston is not mechanically fixed. Such a machine may be of the completely free-piston type, in which neither the inner nor the outer dead point is so fixed, or of the semi-free-piston type as exemplified in British patent to Pescara, No. 557,206. The invention is especially, but not exclusively, concerned with internal-combustion-operated generators of motive gas, in which at least part of the air delivered by the compressor portion is employed to scavenge and charge the internal-combustion portion, the hot products of combustion and the excess of scavenging air discharged at superatmospheric pressure from the power cylinder together forming the motive gas generated, which may be, for example, employed to perform mechanical work by expansion in a turbine.

The nature of the invention will be discussed with reference to some of the accompanying drawings, in which:

Fig. 1 is a diagrammatic sectional side elevation of an opposed-piston type of internal-combustion-operated compression-ignition gas-generator generally of known type, but modified in accordance with this invention, the section being generally in a vertical plane, but the middle part being taken on the line 1—1 in Fig. 6.

Figs. 2 to 5 are graphs illustrating the operation of this gas-generator. In each of these graphs the abscissa shows working pressure P in lbs. per sq. in. absolute, while the abscissa meets the ordinate scale at the zero point of the latter.

Fig. 6 is a cross section on the line 6—6 in Fig. 1 drawn to a larger scale in rather less diagrammatic form.

Fig. 7 shows diagrammatically part of a control system of the same gas-generator.

Fig. 8 is a diagrammatic sectional side elevation of the middle part of an alternative form of gas-generator embodying this invention.

Fig. 9 is a diagrammatic sectional end elevation of the cushion control gear of the gas-generator shown in Figs. 1 and 6, taken on the line 9—9 in Fig. 10, and

Fig. 10 is a section on the line 10—10 in Fig. 9.

The gas-generator shown in Fig. 1 has a power cylinder 10 co-operating with opposed power pistons 11A and 11B which control respectively inlet ports 12 and exhaust ports 13. The power cylinder is mounted co-axially within a cylindrical casing 14 which forms the shell of a scavenge air receiver 15 communicating directly with the inlet ports 12. The exhaust ports 13 are connected by a manifold 16 to a delivery connection 17 for the motive gas, which communicates with the inlet connection of a turbine (not shown). On the end walls 18A and 18B of the scavenge air receiver are mounted, co-axially with the power cylinder 10, combined compressor and cushion cylinders 19A and 19B co-operating with pistons 20A and 20B which are rigidly coupled by rods 21A and 21B to the power pistons 11A and 11B respectively. The inner portions of the cylinders 19A and 19B act as scavenge air compressors, being provided with inlet valves, such as 22A and 22B, and delivery valves, such as 23A and 23B, the latter delivering directly to the scavenge air receiver 15. The outer portions of the cylinders 19A and 19B serve as pneumatic cushions which during each expansion stroke of the power pistons 11A and 11B store the energy necessary to return the free-piston assemblies through the following stroke when the compressor portions perform their delivery stroke and the power pistons their compression stroke.

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The opposite movements of the free-piston assemblies are synchronised by a known system including two levers 24 and 24' capable of oscillating equally and oppositely about a common transverse axis. The ends of the lever 24 are coupled by connecting rods 25A and 25B to cross-heads 26A and 26B fixed respectively on the piston rods 21A and 21B. The ends of the lever 24' are similarly coupled to the cross-heads 26A and 26B by connecting rods 25'A and 25'B. The piston assemblies are prevented from rocking about the axis of the cylinders by arms 27A and 27B co-operating with slide bars 28A and 28B on the casing 14. A fuel-injection nozzle is denoted by 29.

This gas-generator, as so far described, is of known type and is adapted to operate in known manner as follows. Starting from the configuration shown in Fig. 1, the combustion products will have been swept from the power cylinder by air entering the inlet ports 12; some of this air will follow the combustion products through the exhaust ports 13; and the working pressures in the receiver 15 and in the power cylinder 10, will be substantially equal to the pressure at which the motive gas is delivered by the gas-generator at the connection 17. The two piston assemblies are now driven towards each other

by expansion of the cushion air compressed in the outer ends of the cylinders 19A and 19B and during this in-stroke the pistons 20A and 20B deliver compressed air through the valves 23A and 23B to the scavenge air receiver 15 while the power pistons 11A and 11B compress a charge of air in the power cylinder. As the piston assemblies approach their inner dead point, a charge of fuel is introduced through the injector 29. Combustion of the fuel is effected by compression ignition, and the expansion of the combustion products in the power cylinder assisted by expansion of the air compressed in the clearance spaces at the inner ends of the cylinders 19A and 19B, drives the piston assemblies apart, the major part of the energy thus imparted to these assemblies being stored in the air cushions. Finally the piston 11B uncovers the exhaust ports 13, and a little later the piston 11A uncovers the inlet ports 12, the cycle thereafter being repeated. It will thus be apparent that compression of the working charge of air takes place in two stages: first from atmospheric pressure to receiver pressure in the compressor cylinders 19A and 19B; and second from receiver pressure to final compression pressure in the power cylinder 10.

In such a gas-generator the working pressure, namely the delivery pressure of the motive gas at the connection 17, and with it the charging pressure existing in the receiver 15, vary, with the load imposed on the generator by the varying demand of the turbine, over a substantial pressure range, for example up to 70 lbs. per sq. in. As a substantially constant final compression pressure in the combustion space of the power cylinder 10 is desirable over the working range, it follows that the compression ratio of that part of the compression which takes place in the power cylinder 10 varies. As the working pressure increases, so does this compression ratio decrease, and consequently the pistons at the inner dead point are farther apart, or farther away from the middle of the cylinder. Fig. 2 shows by the full line how the distance (plotted as ordinate) of the inner dead point (IDP) of the heads of the pistons 11A and 11B from the middle of the power cylinder varies with working pressure P. The clearance volume of the inner end of the compressor cylinders 19A and 19B at the inner dead point must also increase as the working pressure increases, and assuming the outer dead point of the pistons to be constant, the result will be that the volume V of air delivered by the compressor pistons per stroke will fall as the working pressure increases, as is indicated by the full line in Fig. 3. Fig. 4 shows by the full line how the total volume V_T of air delivered per unit time varies with the working pressure, while the full line in Fig. 5 is a curve plotted in terms of horse-power in the motive gas (G. H. P.) over the same range.

An object of this invention is to provide an improved internal-combustion machine of the kind specified and adapted to work with a varying charging pressure, in which means are provided for reducing variations in the inner dead point of the free pistons, or alternatively in the final compression pressure in the power cylinder, due to variations in charging pressure, whereby the output can be increased, as compared with known machines, over the higher range of charging pressures.

A further object is to provide a free-piston gas-generator in which the compressor part performs its delivery strokes simultaneously with the compression strokes in the motor part, under the influence of energy taken from the free pistons during each expansion stroke in the motor part and stored in a pneumatic energy accumulator for return to the free pistons during the immediately succeeding stroke, and in which nevertheless the clearance volume in the compressor cylinder at the inner dead point is not undesirably increased as the working pressure rises.

Further objects of the invention will be apparent from the following description of two specific embodiments thereof.

Some of the novel features, provided in accordance with this invention, of the generally known gas-generator shown in Fig. 1 will now be described with reference to Figs. 1 and 6. Two auxiliary chambers 30 and 30' are adapted to communicate with the middle part of the power cylinder 10, which forms the main combustion chamber, by ports 31 and 31'. These two chambers are diametrically opposed in the medial transverse plane of the power cylinder, and their axis is inclined to the axis of the synchronising levers 24 and 24' in such a manner as to accommodate also in the same plane two diametrically opposed fuel-injection nozzles 29 and 29', one of said chambers and one of said nozzles being on one side of the lever axis, and the other of each on the other side. As these chambers are identical, only chamber 30 will be described in detail.

The port 31 is formed in a cup 32 of heat-resisting metal fitted with clearance in a socket 33 in the power cylinder 10, which is fitted within a cylinder housing 34. A domed cover 35, secured to the housing 34 by screw studs 36, cooperates with the cup 32 to form the auxiliary chamber 30. A poppet valve 37 has a face 38 adapted to engage a seating 39 surrounding the port 31 at its side within the cup. The stem of the valve 37 passes through a gland 40 in the cover 35. At the inner end of the gland is a seating 41, adapted to be engaged by a face 42 on the head of the valve 37. The valve stem is fixed to a piston 43 operating in a double-acting servo-motor cylinder 44 and urged towards the axis of the power cylinder 10 by a helical compression spring 45. Oil transfer pipes 46 and 47 communicate with the cylinder 44 on the outer and inner sides respectively of the piston 43.

When the working pressure of the gas-generator is low, oil pressure is released (in a manner hereinafter described) in the pipes 47 and may be applied to the pipes 46 from a source 49 (Fig. 7) of oil at constant pressure, which provides the energy for operating the servo-motors, in order to supplement the action of the springs 45, with the result that the valves 37 are held on the seatings 39, and so isolate the auxiliary chambers 30 and 30' from the main combustion chamber. The gas-generator now operates in the normal way. When the working pressure rises to a predetermined value, oil pressure is released in the pipes 46 and applied to the pipes 47, so that the valves 37 are disengaged from the seatings 39 and held on the seatings 41 adjacent to the glands 40. As a result the auxiliary chambers are put into communication with the main combustion chamber. Now the total volume of the combustion chamber at the inner dead point, namely the volume to which the air charge is compressed, will remain the same as in an engine not having the auxiliary chambers but otherwise

equivalent, but that portion of it contained in the main combustion chamber will be reduced by the volume of the auxiliary chambers. The result is that the pistons will come closer together at the inner dead point than they would have done in the absence of the auxiliary chambers, and consequently the clearance volumes at the inner ends of the cylinders 19A and 19B will also be kept small, instead of increasing with increasing working pressure so that the volume of free air delivered by the compressor portion will be largely maintained as the working pressure rises. The dotted lines in Figs. 2 to 5 show the performance when the auxiliary chambers are operative and indicate how the output is increased over the range of higher working pressures.

If the machine were run with the auxiliary chambers operative when the working pressure was low, there would be a risk of the power pistons touching each other at the inner dead point. Consequently it is desirable to provide control mechanism which ensures that the auxiliary chambers are inoperative when the working pressure is low. Such a mechanism is shown in Figs. 6 and 7. The valves 37 are capable of being kept closed by the springs 45, even if the oil pressure in the pipes 46 should fail. The springs 45 need not exert a force sufficient to withstand the peak pressure in the combustion chamber, provided the oil system is arranged to provide a degree of damping sufficient to prevent substantial opening of the valves 37 during the period of peak pressure. The control mechanism shown in Fig. 7 includes a pilot piston valve 48 adapted in the position shown, to connect the pipes 46 to the source 49 of oil under pressure and the pipes 47 to a sump, and in an alternative position to connect the pipes 47 to the source 49 and the pipes 46 to the sump. The valve 48 is controlled by a piston 50 operating in a cylinder 51. The piston 50 is biased by a spring 52 towards the position shown and is urged in the opposite direction by the scavenge air pressure applied to the cylinder 51 by a pipe 53 opening through the scavenge air receiver casing 14. A spring-loaded ball 54 co-operates with two notches in the stem of the valve 48. When the scavenge air pressure acting on the piston 50 rises to a predetermined value, it overcomes the restraint of the spring 52 and the ball 54 and moves the pilot valve 48 to the left. The servo-motor pistons 43 thereupon open the valves 37 so that the auxiliary chambers 30 and 30' become operative. When the scavenge air pressure falls to a predetermined value, the pilot valve is restored by the spring 52 to the position shown, and the valves 37 are accordingly shut.

The gas-generator shown in Figs. 1 and 6 is provided with automatic control gear for varying the quantity of air in the cushions in accordance with variation in the working pressure. This control gear may be of any suitable type; but it will be assumed that it is the one described in patent application No. 492,865 of E. S. L. Beale filed June 30, 1943, and the control gear will therefore be described only in so far as it concerns the present invention. Referring to Fig. 6, the control gear is contained within a casing 55, and it is capable of delivering air to, or withdrawing air from, a pipe 56 branching to pipes 57A and 57B which lead to the cushions. The quantities of air so delivered and withdrawn are determined automatically by variation both in the scavenge air pressure and also in the inner dead point of the free pistons. The scavenge air

pressure is applied from the scavenge air receiver through an orifice 58 to a pressure-responsive bellows 100. A spiral cam 59 fixed on the shaft 60 of the synchronising lever 24 actuates a tappet 61, the displacement of which is directly proportional to the displacements of the free-piston assemblies; therefore variation in the inner dead point of the tappet stroke is also directly proportional to variation in the inner dead point of the free-piston assemblies. The tappet actuates a device 101 having an output member 102 which is adapted to follow variations in the inner dead point of the tappet. The inner-dead-point follower 101 and the bellows 100 are arranged to control the cushion air content through a differential mechanism consisting of a lever 103 having its ends operatively connected by rollers 104 and 105 to cross-heads 106 and 107 on the output members of the follower 101 and the bellows 100. The lever 103 is pivoted to a slide bar 108 which is connected by a multiplying lever 109 to a hydraulic relay. This relay consists of a double-acting piston 110 operating in a cylinder 111 under control of a valve 112. This valve is actuated by a floating lever 113 which is connected by a link 114 to the multiplying lever 109 and which derives a return motion from the piston 110 by means of a pin-and-slot connection 115 to the piston rod 116. A transfer valve actuated by the rod 116 has two piston lands 117 and 118 which normally close ports 119 and 120 communicating respectively through oppositely acting non-return valves 121 and 122 with the chamber 123 to which the scavenge air pressure is admitted through the orifice 58. The transfer valve also has a port 124 opening between the lands and connected to the cushion pipe 56. In operation, the cushion air pressure oscillates, in synchronism with the reciprocation of the free pistons, between a maximum value which exceeds, and a minimum value which is less than, the scavenge air pressure. Variation of the inner dead point or of the scavenge air pressure causes the transfer valve to move appropriately. If this valve rises, it connects port 119 to port 124. Consequently, during the part of the cycle when the scavenge air pressure exceeds the cushion pressure, air is transferred through the non-return valve 121 to the cushions until the transfer valve is again closed by the cushion air contents rising to a suitable value. Similarly, if the transfer valve falls, air is discharged from the cushion through the port 120 and the non-return valve 122 during the part of the cycle when the cushion pressure is higher than the scavenge air pressure.

The increase in the clearance volume of the power cylinder 10 caused by rendering the auxiliary chambers 30 and 30' operative, has the effect of reducing the distance of the inner dead point from the middle of the power cylinder 10 required for a given compression ratio. If no steps were taken to alter the adjustment of the inner-dead-point control gear, the inner-dead-point follower tappet 61 would attain an inner dead point such as to indicate to the control gear that the inner dead point of the free pistons was too small (i. e. the inner dead point was too near the middle of the power cylinder) when in fact it was correct, and would operate on the control gear to cause air to be withdrawn from the cushions, so that the compression ratio would be automatically reduced. Consequently according to a further feature of the invention, means are provided which alter the adjustment of the inner-

dead-point control gear simultaneously with the rendering of the auxiliary chambers operative, in such a way as to maintain the same compression ratio as existed before the auxiliary chambers were operative. Fig. 7 shows such means. The tappet 61 is provided with a cam follower 62 the head of which is formed as a piston 63 operating in a cylindrical cavity in the tappet between stops 64 and 65. A relatively strong compression spring 66 is adapted to hold the cam-follower 62 continuously in the extended position shown. The lower end of the cylindrical cavity communicates by a port 67 with a channel 68 in the tappet guide 69, and the channel 68 is connected by a pipe 70 to the oil-transfer pipes 47 of the servo-motor cylinders 44. Consequently, when the pilot valve 48 operates to allow oil under pressure to flow to the pipes 47, and thus open the valves 37 of the auxiliary chambers, oil under pressure is also admitted beneath the piston 63 of the cam-follower 62 which is thereby retracted into the tappet through the distance that will correct the relationship between the free-piston position and the tappet position, so as to take account of the change in inner dead point made necessary by the bringing into operation of the auxiliary chamber. When the oil pressure is released from the pipe 70 on closing of the valves 37 of the auxiliary chambers, the cam-follower 62 is again extended with respect to the tappet 61 by the spring 66, which is strong enough to prevent movement of the cam follower into the tappet throughout their working stroke.

In accordance with the invention, the effective volume of the auxiliary combustion space may be progressively increased. This result may be attained by putting two or more auxiliary chambers successively into operation. Alternatively, the auxiliary chamber may be constituted by a cylinder communicating with the main combustion chamber, if desired through a valve-controlled port, and containing a piston which is capable of being moved between various positions of adjustment for the purpose of varying the effective volume of the auxiliary chamber, whereby the inner dead point of the combustion pistons can be maintained approximately constant over the whole range of working pressure. Such an arrangement is shown in Fig. 8, where the auxiliary chamber 30A is formed by a piston 71 in a cylinder 72, the lower end of which communicates with the main combustion chamber by a port 31A in the power cylinder 10. The inner face of the piston 71 is provided with a valve facing 38A adapted to seal the port 31A when the piston 71 is in its lowest position. The effective volume of the auxiliary chamber 30A is adjusted by a shaft 73 operated either by hand or by automatic means hereafter described and carrying a bevel wheel 74 which meshes with a bevel wheel 75 having internal splines mating with a splined portion 76 of the rod of the piston 71. A screwed portion 77 of this rod is engaged in a screw-threaded boss 78 on the cap of the cylinder 72.

In order to prevent risk of the power pistons hitting each other through operating with a large auxiliary chamber volume when the working pressure is low, means are provided for automatically disabling the fuel-injection system under such circumstances. The injection nozzle 29 is supplied through a pipe 79 by an injection pump (such as 80 in Fig. 6 driven off the shaft of the synchronising lever 24'). A hydraulically controlled spill valve 81 on the pipe 79 is normally kept closed by oil pressure in a pipe 82. A piston valve 83 normally opens the pipe 82 to a source 84 of oil under pressure. The piston valve 83 is controlled jointly by a compression spring 85 and a lever 86 one end of which bears on the end of the rod of the piston 71 and the other end of which is pivotally connected to the rod of a piston 87 working in a cylinder 88. A spring 89 urges the piston 87 upwards against the scavenge air pressure applied to its upper face by a duct 90. If the relationship between scavenge air pressure and effective volume of the chamber 30A departs from predetermined limits, the valve 83 closes and the oil pressure in the pipe 82 is released by a leak 91, so that the spill valve 81 opens and the machine stops. The piston 87 may be operatively connected to the control shaft 73 by a repeater mechanism of any desired type, indicated schematically at 92, and deriving its return motion from the lever 86. This mechanism, on displacement of the valve 83 due to variation of the scavenge air pressure acting on the piston 87, rotates the shaft 73 in such a sense as to restore the valve 83 to the normal position shown, and, as the valve attains this position, the return connection operates to stop the repeater mechanism. In this manner the effective volume of the chamber 30A can be caused to vary automatically in response to variation of the scavenge air pressure, the spill valve 81 opening on failure of the repeater mechanism.

I claim:

1. An internal-combustion-operated motive-gas generator having a power cylinder including a combustion chamber, an air-compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison in such a manner that said compressor piston performs its delivery strokes simultaneously with the compression strokes of said power piston, a pneumatic cushion associated with said pistons for storing energy imparted to them during the expansion strokes of said power piston and returning energy to said pistons during the compression strokes of said power cylinder, means for causing at least a part of the air compressed in said compressor cylinder to scavenge and charge said power cylinder, an auxiliary chamber capable of communicating with said combustion chamber, valve means for interrupting communication between said chambers, and control means operable for varying the volume of said auxiliary chamber.

2. An internal-combustion-operated reciprocating machine having a power cylinder open at each end, a pair of power pistons slidable in said power cylinder, synchronising means for constraining said pistons to move oppositely and including a pair of members oscillable about a common synchroniser axis normal to the axis of said cylinder, said members being disposed on opposite sides of said cylinder, an air compressor cylinder co-axial with said power cylinder, a compressor piston connected to one of said power pistons for movement in unison therewith and slidable in said compressor cylinder, said compressor piston being arranged to perform its delivery strokes simultaneously with the compression strokes of said power pistons, means for causing at least part of the air compressed

in said compressor cylinder to scavenge and charge said power cylinder, a pneumatic cushion associated with one of said pistons for storing energy of combustion in said power cylinder and returning energy to said pistons during said compression strokes, an auxiliary chamber capable of communicating with the middle portion of said power cylinder, the axis of said auxiliary chamber being inclined with respect to said common synchroniser axis, a valve for interrupting communication between said chamber and said power cylinder, and a fuel-injection nozzle communicating with the middle portion of said power cylinder and disposed on the same side of said common synchroniser axis as said chamber, the axis of said nozzle being inclined oppositely to said chamber axis with respect to said common synchroniser axis.

3. An internal-combustion-operated reciprocating machine having a power cylinder open at each end, a pair of power pistons slidable in said power cylinder, synchronising means for constraining said pistons to move oppositely and including a pair of members oscillable about a common synchroniser axis normal to the axis of said cylinder, said members being disposed on opposite sides of said cylinder, an air compressor cylinder co-axial with said power cylinder, a compressor piston connected to one of said power pistons for movement in unison therewith and slidable in said compressor cylinder, said compressor piston being arranged to perform its delivery strokes simultaneously with the compression strokes of said power pistons, means for causing at least part of the air compressed in said compressor cylinder to scavenge and charge said power cylinder, a pneumatic cushion associated with one of said pistons for storing energy of combustion in said power cylinder and returning energy to said pistons during said compression strokes, two auxiliary chambers diametrically opposed about the axis of said power cylinder and capable of communicating with the middle portion of said power cylinder, two valves for interrupting communication between said auxiliary chambers respectively and said power cylinder, and two fuel-injection nozzles diametrically opposed about the axis of said power cylinder and communicating with said power cylinder, the axes of said chambers and of said nozzles and said common synchroniser axis lying substantially in a common plane normal to said power-cylinder axis in such a manner that one of said chambers and one of said nozzles lie on one side of said synchroniser axis and the other of said chambers and the other of said nozzles lie on the other side of said synchroniser axis.

4. An internal-combustion-operated reciprocating machine having a power cylinder including a combustion chamber, a compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison as a piston assembly so controlled that the inner dead point of said power piston is unconstrained mechanically, means for charging said power cylinder at a variable pressure, an auxiliary chamber having a port for communication with said combustion chamber, a poppet valve having a head disposed within said auxiliary chamber for sealing said port and a stem passing through a gland in the wall of said auxiliary chamber, a spring biasing said valve towards its closed position, power operated means for opening said valve, and means serving in response to reduction of said charging pressure to below a given value to de-energize said power operated means.

5. An internal-combustion-operated reciprocating machine having a power cylinder including a combustion chamber, a compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison as a piston assembly so controlled that the inner dead point of said power piston is unconstrained mechanically, means for charging said power cylinder at a variable pressure, an auxiliary chamber capable of communicating with said combustion chamber, valve means for interrupting communication between said chambers, and a device responsive to variation of said charging pressure for opening said valve automatically when said charging pressure rises to a predetermined value.

6. An internal-combustion-operated reciprocating machine having a power cylinder including a combustion chamber, a compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison as a piston assembly so controlled that the inner dead point of said power piston is unconstrained mechanically, means for charging said power cylinder at a variable pressure, an auxiliary chamber capable of communicating with said combustion chamber, and control means for automatically rendering said auxiliary chamber inoperative in consequence of reduction of said charging pressure below a predetermined value.

7. An internal-combustion-operated reciprocating machine having a power cylinder including a combustion chamber, a compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison as a piston assembly so controlled that the inner dead point of said power piston is unconstrained mechanically, means for charging said power cylinder at a variable pressure, an auxiliary chamber having a port for communication with said combustion chamber, a poppet valve having a head disposed within said auxiliary chamber for sealing said port and a stem passing through a gland in the wall of said auxiliary chamber, a spring biasing said valve towards its closed position, and a double-acting hydraulic servo-motor operatively connected with said valve and capable of serving as a hydraulic damper in the event of loss of pressure of its operating liquid.

8. An internal-combustion-operated reciprocating machine having a power cylinder including a combustion chamber, a compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison as a piston assembly so controlled that the inner dead point of said power piston is unconstrained mechanically, means for charging said power cylinder at a variable pressure, an auxiliary chamber having a port for communication with said combustion chamber, a poppet valve having a head disposed within said auxiliary chamber for sealing said port and a stem passing through a gland in the wall of said auxiliary chamber, a

spring biasing said valve towards its closed position, a double-acting servo-motor operatively connected with said valve, and a reversing controller for said servo-motor automatically responsive to variation in said charging pressure.

9. An internal-combustion-operated motive-gas generator having a power cylinder including a combustion chamber, an air-compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison in such a manner that said compressor piston performs its delivery strokes simultaneously with the compression strokes of said power piston, a pneumatic cushion associated with said pistons for storing energy imparted to them during the expansion strokes of said power piston and returning energy to said pistons during the compression strokes of said power cylinder, means for causing at least a part of the air compressed in said compressor cylinder to scavenge and charge said power cylinder, an auxiliary chamber communicating with said power cylinder, and control means responsive to variation in the delivery pressure of said compressor cylinder for automatically rendering said auxiliary chamber inoperative in consequence of reduction of said delivery pressure below a predetermined value.

10. An internal-combustion-operated reciprocating machine having a power cylinder including a combustion chamber, a compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison as a piston assembly so controlled that the inner dead point of said power piston is unconstrained mechanically, means for charging said power cylinder at a variable pressure, control mechanism including an adjustable follower device for following variations in said inner dead point, an auxiliary chamber capable of communicating with said combustion chamber, control means for rendering said auxiliary chamber alternatively operative and inoperative, and compensating means associated with said follower device and with said control means for altering the adjustment of said follower device automatically and simultaneously with the rendering of said auxiliary chamber operative and inoperative in such a way as to maintain substantially the same compression ratio in said power cylinder.

11. An internal-combustion-operated motive-gas generator having a power cylinder including a combustion chamber, an air-compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison in such a manner that said compressor piston performs its delivery strokes simultaneously with the compression strokes of said power piston, a pneumatic cushion associated with said pistons for storing energy imparted to them during the expansion strokes of said power piston and returning energy to said pistons during the compression strokes of said power cylinder, means for causing at least a part of the air compressed in said compressor cylinder to scavenge and charge said power cylinder, control mechanism including an adjustable follower device for following variation in the inner dead point of said power piston, an auxiliary chamber capable of communicating with said combustion chamber, servo mechanism for rendering said auxiliary chamber alternatively operative and inoperative, and compensating means associated with said follower device and said servo mechanism for altering the adjustment of said follower device automatically and simultaneously with the rendering of said auxiliary chamber operative and inoperative in such a way as to maintain substantially the same compression ratio in said power cylinder.

12. An internal-combustion-operated motive-gas generator having a power cylinder including a combustion chamber, an air-compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison in such a manner that said compressor piston performs its delivery strokes simultaneously with the compression strokes of said power piston, a pneumatic cushion associated with said pistons for storing energy imparted to them during the expansion strokes of said power piston and returning energy to said pistons during the compression strokes of said power cylinder, means for causing at least a part of the air compressed in said compressor cylinder to scavenge and charge said power cylinder, control mechanism including an oscillable element of variable effective length for following variation of the inner dead point of said power piston, a hydraulic control device for varying said effective length, an auxiliary chamber capable of communicating with said combustion chamber, hydraulic servo mechanism for rendering said auxiliary chamber alternatively operative and inoperative, and a compensating connection for liquid between said hydraulic control device and said hydraulic servo mechanism which causes the effective length of said oscillable follower element to be varied automatically and simultaneously with the rendering of said auxiliary chamber operative and inoperative in such a way as to maintain substantially the same compression ratio in said power cylinder.

13. An internal-combustion-operated reciprocating machine having a power cylinder including a combustion chamber, a compressor cylinder co-axial with said power cylinder, a power piston and a compressor piston slidable in said cylinders respectively, said pistons being connected together for operation in unison as a piston assembly so controlled that the inner dead point of said power piston is unconstrained mechanically, means for charging said power cylinder at a variable pressure, a control member operable for stopping the machine, an auxiliary chamber capable of communicating with said combustion chamber, control means for rendering said auxiliary chamber alternatively operative and inoperative, and protective mechanism operatively associated with said stop control member and said control means and responsive to variation in said charging pressure for automatically stopping the machine in response to the occurrence of an undesired relationship between said charging pressure and the effective volume of said auxiliary chamber.

FREDERICK ALAN IRVING MUNTZ.