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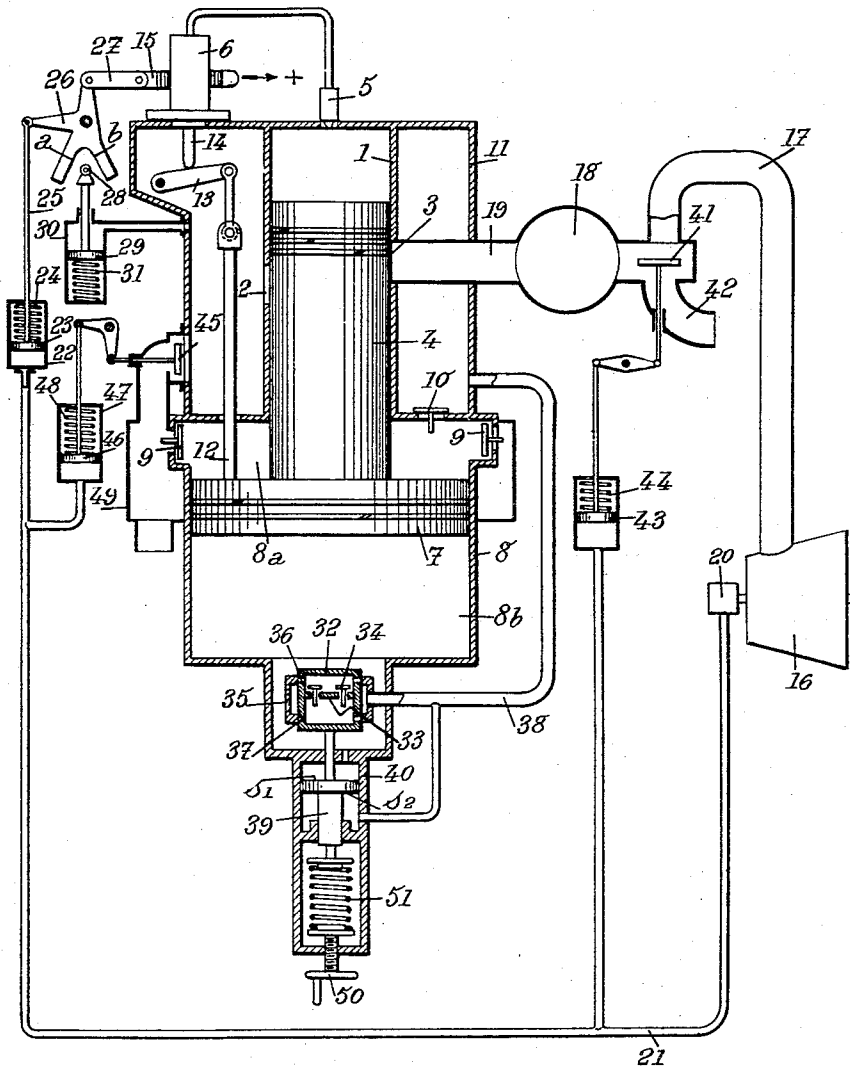
H. HORGEN
GAS-GENERATORS OF THE INTERNAL-COMBUSTION-OPERATED
FREE-PISTON TYPE

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2 Sheets-Sheet 1

Fig. 1.



INVENTOR
Herge Horgen
BY
Bailey Stephens and Huttig
ATTORNEYS

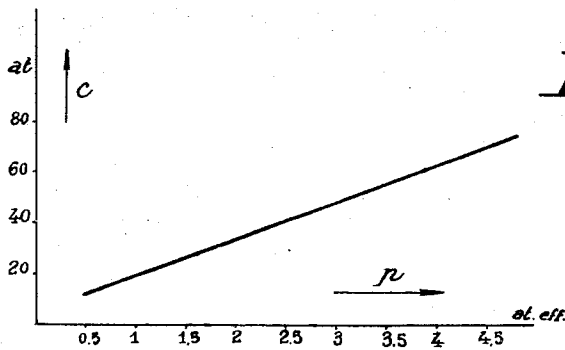
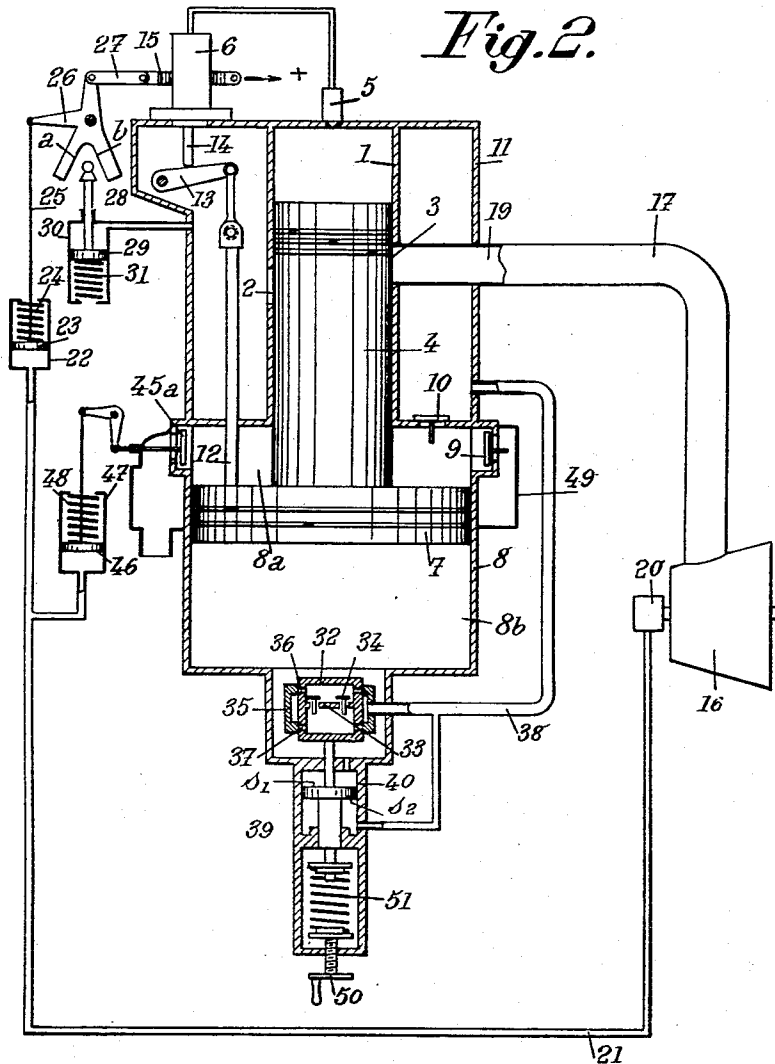
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INVENTOR

Herge Horgen

BY

Bradley Stephens and Stratton
ATTORNEYS

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GAS-GENERATORS OF THE INTERNAL-COMBUSTION-OPERATED FREE-PISTON TYPE

Helge Horgen, Lyons, France, assignor to Societe d'Etudes et de Participations Eau, Gaz, Electricite, Energie S.A., Geneva, Switzerland, a society of Switzerland

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4 Claims. (Cl. 60—13)

This invention relates to gas-generators of the internal-combustion-operated free-piston type, that is to say to machines comprising a power part operating on the Diesel principle and having a two-stroke cycle, and a compressing part which compresses air wholly or mainly employed to supply and scavenge the power part. The gases which issue from the exhaust ports of the last-mentioned part and which consist of a mixture of combustion gases and the excess of scavenging air constitute the power gases supplied by the said generator and serving to drive a receiving engine such, for example, as a turbine.

It is known that the delivery from the gas-generator can be adapted, as regards both the pressure and also the quantity of the power gases, to the requirements of the receiving engine over a fairly wide load range thereof, merely by regulation of the quantity of fuel which is introduced into the cylinder of the power part of the gas-generator. On the other hand, for idle running and light loading of the receiving engine the minimum delivery from the gas-generator, when arranged in known manner, exceeds the swallowing capacity of the receiving engine, with the result that, for these working conditions, the surplus of gas delivered by the gas-generator must be allowed to escape.

A main object of this invention is to reduce and even completely to eliminate the said surplus which occurs with light loading and idle running of the receiving engine.

According to my invention, in a gas-generator of the above stated type, including means for varying the final pressure produced by the compression in the power cylinder of said gas-generator, I provide means for heating the air supplied to the said cylinder when the receiving engine fed with power gas from the gas-generator runs idly or with a light load, such means being brought into action simultaneously with means for reducing the final compression pressure in the power cylinder below the minimum value necessary for effecting self-ignition of the fuel in conventional Diesel engines, the said reduction in the said final pressure causing on the one hand a reduction in the number of cycles (outward and inward strokes) per unit of time of the free piston or pistons of the gas-generator and, on the other hand, causing an outward displacement of the inner dead point, with a resultant decrease in compressor delivery per stroke.

The invention will be readily understood with reference to the following description and to the accompanying drawings, which description and drawings are of course given by way of example.

In the drawings:

Figs. 1 and 2 illustrate diagrammatically and in longitudinal section respectively two constructional forms of a free-piston gas-generator constructed according to the invention and forming part of an installation wherein the power gases produced by the gas-generator serve to drive a turbine, and

Fig. 3 is a diagram to aid in a better understanding of the invention.

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The general construction of the gas-generator comprises in conventional manner a power part operating on the two-stroke Diesel principle and comprising a power cylinder 1 having inlet ports 2 and exhaust ports 3, while a power piston 4 forming part of a free-piston assembly operates within the cylinder 1. The piston 4 covers the ports 2 and 3 in conventional manner when in the neighbourhood of its outer dead point. In addition, a fuel injector 5 supplied by an injection pump 6 is disposed at the end of the power cylinder 1.

The free-piston assembly of the machine comprises, in addition to the power piston 4, a compressor piston 7 which operates in a compressor cylinder 8 divided by the piston 7 into two chambers. One of these chambers 8a forms the compressor chamber proper and has intake valves 9, through which the to be compressed is drawn, and delivery valves 10 fitted in a separating wall between the chamber 8a and a casing 11 which surrounds the power cylinder 1 and receives the air compressed by the piston 7 within the chamber 8a, the latter air serving to supply and scavenge the driving cylinder 1.

The second chamber 8b in the compressor cylinder 8 contains an air cushion which stores the energy of the piston 4 when the latter performs its outward stroke under the influence of the combustion of the fuel in the power cylinder 1, and which returns the said energy to the free-piston assembly 4, 7 during the inward stroke thereof during which there occurs the compression of air in the chamber 8a, the delivery of the latter air into the casing 11 and the compression of the combustion air contained in the power cylinder 1 after the piston 4 has closed the ports 2 and 3 in the cylinder 1.

The injection pump 6 is driven by means of a rod 12 fast with the compressor piston 7, a rocking movement being imparted to a lever 13 which, through a push-rod 14, acts upon the piston of the pump 6. Regulation of the quantity of fuel supplied by the pump 6 through the injector 5 to the power cylinder 1 each time the power piston 4 is near its inner dead point is effected in conventional manner by means of an axially-movable member 15 which may, for example, be a rack causing the piston of the pump 6 to rotate about its axis. The quantity of fuel injected per cycle of piston movement is greater in proportion as the rack 15 is moved to the right, that is in the direction of the arrow +.

The rack 15 can be moved by any desired appropriate means, for example by hand. However, movements of the rack 15 are preferably effected automatically in dependence upon the speed of the receiving engine driven by the power gases delivered by the gas-generator and constituted, in the embodiment illustrated in Figs. 1 and 2, by a gas turbine 16, the inlet of which is connected, through a pipe 17, an intermediate reservoir 18 and a pipe 19, to the exhaust ports 3 of the power cylinder of the gas-generator. In order to effect automatic control of the pump-regulating rod 15, the turbine speed regulator 20 (for instance a fluid compressor driven by said turbine) is arranged to apply a fairly high pressure to a fluid, preferably a liquid, in a pipe 21 connecting the regulator 20 to a cylinder 22 in which operates a piston 23 which is subjected to the action of a return spring 24, and the rod 25 of which is articulated to one of the arms of a bell-crank lever 26, the other arm thereof being connected through a short rod 27 to the regulating rod 15. The regulator 20 is so arranged that, with increase in load on the turbine 16, the pressure in the pipe 21 increases and the rod 15 is moved increasingly to the right in the direction indicated by the arrow +.

However, it is known that regulation of the fuel injected into the gas-generator must remain within certain limits which are variable in dependence upon the working pressure of the gas-generator. This working pressure

is either the pressure in the casing 11, the pressure in the exhaust pipe 19 (the difference between the two latter pressures is negligible and can therefore be neglected), or any other pressure which varies in dependence upon either of the above-mentioned pressures.

In order that the fuel regulation associated with movement of the rod 15 may remain within the said limits, the bell-crank lever 26 is fast with a double cam forming approximately a V, the said cam co-operating with a stop 28, the position of which is varied in dependence upon the pressure in the casing 11. To this end the stop 28 is carried by a piston 29 which operates in a cylinder 30 and one face of which is acted upon by the said pressure, the other face being subjected to the influence of a return spring 31. Engagement of the surface *a* of the double cam with the stop 28 determines the minimum value to which the quantity of fuel injected can be reduced, while engagement of the face *b* with the said stop prevents the quantity of fuel injected from exceeding a maximum permissible value. As long as the stop 28 is out of contact with the surfaces *a* and *b*, the position of the regulating rack 15 depends only upon the control pulses received from the speed regulator 20 of the turbine 16.

It is known that the mass of air forming the cushion of the energy accumulator 8*b* has to be controlled in dependence upon the working pressure of the gas-generator in order that the latter may operate in a stable manner. It is also known so to control the air mass in the said cushion that the final pressure reached in the power cylinder at the end of the compression stroke of the power piston 4 increases when the above-mentioned working pressure increases and vice versa. These controls are effected by means of a device known as a stabilizer which mainly comprises a slide valve 32 divided by a separating wall 33 into two chambers, the wall 33 having one or more check valves 34. The slide valve moves in a valve chest 35 in such manner that one or the other of the two chambers inside the said slide valve can be placed in communication, by way of apertures 36 and 37, with the inside of the chest 35. The latter is connected through a pipe 38 to the casing 11. Hence, depending upon the position of the slide valve 32, some air can escape out of the cushion 8*b* into the engine case 11 or can be introduced therefrom into the cushion 8*b*. The slide valve 32 is actuated in known manner by a stepped piston 39 disposed inside a cylinder 40. Acting upon the larger face *s*₁ of the stepped piston 39 is the mean pressure in the cushion 8*b* or the pressure prevailing therein for a given position of the piston 7, while acting upon the smaller face *s*₂ of the stepped piston is the pressure in the casing 11 which may be considered as corresponding to the working pressure of the gas-generator. If the ratio between the surfaces *s*₁ and *s*₂ of the stepped piston 39 is suitably chosen, the variation of the final compression in the power cylinder 1 in response to variation of the gas-generator working pressure can be made to follow any desired law.

When the load of the turbine 16 is between a medium value and its maximum value, the installation is regulated exclusively by movement of the regulating rack 15 controlled by the regulator 20. For such working conditions, the delivery from the gas-generator can always be completely adapted to the requirements of the turbine 16 owing to the fact that it is possible to vary the length of stroke of the free-piston. This state of affairs alters when the generator is idling or running with very small loads, that is to say for loads such that the pressure of the delivery from the gas-generator lies between 0.5 and 1.5 atmospheres for example. In this case, the minimum delivery from the gas-generator (that is to say the delivery when the outer dead point of the free piston is such that the ports 2 and 3 are opened by the piston by an amount only just sufficient

for the supply and scavenging of the power cylinder) is greater than the delivery which the turbine 16 can swallow at the said low loads if special steps are not taken. Heretofore, after shortening the piston stroke as much as possible, the only other step has been to allow the surplus power gases delivered for such loads by the gas-generator to escape by way of a valve fitted, for example, in the piping connecting the exhaust ports 3 to the inlet of the turbine 16. A valve 41 of this kind is illustrated in Fig. 1 as being fitted between the reservoir 18 and the pipe 17. When the valve 41 is open, some of the gases delivered by the generator can escape to atmosphere at 42. The valve 41 is controlled, for example, by a piston 43, one face of which is acted upon by the pressure of the fluid in the pipe 21, while the other face of the piston 43 is acted upon by a return spring 44. By a suitable choice of the force of the spring 44, the arrangement can be made such that the valve 41 opens at reduced loads, the opening of the valve 41 increasing in proportion as the load is reduced and the valve 41 closing above a predetermined moderate load, with the result that from this point all the gases delivered by the gas-generator reach the turbine 16.

It is obvious that the gases which escape, when the installation is lightly loaded or idling, past the valve 41 and through pipe 42 to atmosphere represent a loss and that it is important to reduce this loss to a minimum. This can be obtained by reducing as much as possible the number of cycles per unit of time (1 cycle=1 outward and 1 return stroke) of the free piston. Now, this number of cycles per unit of time of the free piston depends essentially upon the final compression pressure in the power cylinder 1 (itself controlled, as above stated, by the stabilizer 32—33—34), this number being the smaller as the said final compression pressure is lower. Heretofore the stabilizer was adjusted so that under all working conditions, even at light loads or when idling, the final compression pressure was still great enough to effect by itself self-ignition of the fuel injected into the engine cylinder. In other words, the final compression pressures during slow running and at light loads ranged from 25 to 30 atmospheres, these being the minimum final compression pressures necessary to obtain self ignition of the fuel in Diesel engines.

According to my invention, in order still further to reduce the losses caused by the discharge of power gas to the atmosphere during idle running and at light loads and even to eliminate such losses, I adjust the stabilizer or equivalent means so that during such periods the final compression pressures in the power cylinder are below the minimum values for ensuring self-ignition of the fuel in conventional working condition, but I provide means for simultaneously heating the air to be supplied to the power cylinder so as to achieve self-ignition of the fuel despite this reduction of the final compression pressure in the power cylinder. In this way, the gas-generator can be made to run very slowly. Furthermore, for a given feed pressure to the power cylinder, when the final compression pressure in the power cylinder is reduced, the power piston during its compression stroke stops at a greater distance from the cylinder head, so that the compressor piston, rigid with said power has its suction stroke shortened which corresponds to a reduction in the delivery of the compressor per stroke thereof greater than anything that could have been obtained up to now. Since the outer dead point of the pistons remains at its most inward possible position, the delivery of power gases is much less than the minimum delivery of known gas-generators which are not arranged according to the present invention. This arrangement according to the invention enables a considerable saving in fuel to be obtained, this saving possibly being 50% or more during idling periods.

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Preferably, the above-mentioned heating (at light loads or when idling) of the air to be fed to the power cylinder is performed before this air enters the compressor cylinder.

Heating of the air supplied to the compressor cylinder can be effected in various ways. For instance, it is possible to use for this purpose the heat contained in the gases which escape through 42 when the valve 41 is open. But, according to a particularly advantageous arrangement, I obtain this heating by admixing some of the compressed air supplied by the compressor to the air fed from the atmosphere to the compressor chamber 8a of the compressor cylinder 8.

For this purpose, in the embodiment of Fig. 1, casing 11 is provided with an exhaust valve 45 actuated by a piston 46 operating in a cylinder 47 and on one face of which acts the pressure in the pipe 21, the other face being subjected to the action of an opposing spring 48. The force of the latter is such that the valve 45 remains closed as long as the pressure in the pipe 21 is above a value corresponding to a moderate load, for example to the load at which the working pressure in the gas-generator is equal to 1.5 atmospheres, this valve 45 opening when the pressure in the pipe 21 drops below this value and this the more so as the pressure in this pipe 21 is lower. Any hot air escaping through the valve 45 when the same is open mixes in a casing 49, which surrounds the intake valves 9 of the chamber 8a of the compressor cylinder, with the air which enters from the outside into the chamber 8a during the suction stroke of the piston 7, with the result that the heating of the air fed to the compressor increases as the turbine loading falls.

As above stated, the stabilizer which controls the final compression pressure in the power cylinder 1 must be so adjusted that during idle running and at light loads these final pressures are below the minimum values which, other things being equal, are capable of ensuring self-ignition of the fuel in the power cylinder. Referring for instance to the graph of Fig. 3, where the working pressures p of the gas-generator (corresponding to the pressure in casing 11, or in pipe 21) are plotted in abscissas, whereas the final pressures c in the power cylinder 1 are plotted in ordinates, it will be seen that for values of the gas-generator working pressure ranging from 0.5 to 1.5 atmospheres, the final compression pressures in the power cylinder 1 range from 12 to 25 atmospheres. Now, under normal operation conditions, that is to say when the air to be fed to the power cylinder 1 is not especially pre-heated (as obtained according to my invention by means of valve 45) such final compression pressures (ranging from 12 to 25 atmospheres) in the power cylinder 1 are insufficient to achieve self ignition of the fuel in the cylinder. But the special pre-heating of this air due to the opening of the valve 45 (controlled by variation of the pressure in pipe 21, i.e. of the gas-generator working pressure) compensates for the effect of such low values of the final compression pressure, with the result that self-ignition takes place in the power cylinder despite the reduced values of final compression pressure therein. In the example in question, it is assumed that above a working pressure of 1.5 atmospheres, at which the final compression pressure in the engine cylinder exceeds 25 atmospheres, the air need no longer be heated in order to ensure self-ignition, so that the valve 45 remains closed for working pressures greater than 1.5 atmospheres. During the period for which the working pressures lie between 0.5 and 1.5 atmospheres, the quantity of fuel injected is determined by the contact between the cam surface a (minimum injection surface) and the stop 28. Only after closure of the valves 45 and 41 does the stop 28 leave the surface of the cam a , the period then beginning during which fuel regulation is effected exclusively by the regulator 20.

In the embodiment illustrated in Fig. 2, the elements corresponding to those hereinbefore described are designated by the same reference numerals.

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The second embodiment differs from the first one in that the exhaust valve 41 is omitted. In fact, in many cases in which the arrangement according to the invention is applied, the exhaust valve 41 can be omitted completely. Furthermore, in the embodiment illustrated in Figure 2 the re-cycled amount of air used to pre-heat the air admitted to the compressor is derived directly from the compressor chamber 8a instead of from the casing 11. For this purpose the valve 45a, which, for light loads and idle running is more or less open, is fitted in the chamber 8a. This arrangement still further reduces the fuel consumed during idle running and more particularly at light loads, but the valve 45a must be of greater cross-section than the valve 45 fitted in the casing 11.

It is obvious that the gas-generator only operates in the manner hereinbefore described when it is at its normal operating temperature. When the gas-generator is cold and has to be started, special means must be provided to effect this starting and to enable the gas-generator to reach its normal operating temperature. For this purpose the gas-generator is provided with an additional device which at starting ensures that the final compression pressure in the engine cylinder is much greater than that produced during idle running or at light loads at the normal operating temperature. The said device comprises, for example, an adjustable wheel 50 which enables tension to be applied to a return spring 51 acting upon the control piston 39 of the stabilizer. Before the gas-generator is started, the tension on the spring 51 is increased in order to obtain a relatively high final compression pressure in the manner conventionally used with a cold engine. As soon as the engine has warmed up sufficiently, the wheel 50 is disengaged and the compression in the engine cylinder is therefore reduced until for idle running the final compression pressure in the latter reaches the value of 12 atmospheres, for example. When a load is subsequently applied to the installation, the stabilizer increases the said final compression pressure in proportion as the working pressure rises, the final compression pressure possibly reaching a value of 75 atmospheres, for example, at full load.

Of course, the gas-generator according to my invention may be of the type comprising opposed free pistons which move in opposite directions in a single engine cylinder and which are synchronized by synchronizing means.

In a general manner, while I have, in the above description, disclosed what I deem to be practical and efficient embodiments of my invention, it should be well understood that I do not wish to be limited thereto as there might be changes made in the arrangement, disposition and form of the parts without departing from the principle of the present invention as comprehended within the scope of the accompanying claims.

What I claim is:

1. An internal combustion operated free piston gas generator which comprises, in combination, a power cylinder, an air compressor cylinder, a power piston for cooperating with said power cylinder, a compressor piston for cooperating with said compressor cylinder, said two pistons being rigid with each other, means controlled by said power piston for feeding compressed air from said compressor cylinder to said power cylinder at the end of the suction stroke of said power piston, means for automatically controlling the final compression pressure in said power cylinder in response to variation of the working pressure of said generator, said last mentioned means being adjusted to give, for values of said working pressure below a predetermined limit value, final compression pressures in said power cylinder lower than those necessary to achieve, in said power cylinder, self ignition of the fuel therein under normal conditions, and means responsive to variation of the working pressure of said generator for admixing, for low values of said working pressure, compressed air from said compressor cylinder with the air admitted from the atmosphere into said

compressor cylinder during the suction stroke of said compressor piston.

2. An internal combustion operated free piston gas generator which comprises, in combination, a power cylinder, an air compressor cylinder, a power piston for cooperating with said power cylinder, a compressor piston for cooperating with said compressor cylinder, said two pistons being rigid with each other, a casing surrounding said power cylinder, at least one passage between said compressor cylinder and said casing, check valve means in said passage opening toward said casing, said power cylinder being provided with at least one port controlled by said power piston for feeding compressed air from said casing to said power cylinder at the end of the suction stroke of said power piston, means for automatically controlling the final compression pressure in said power cylinder in response to variation of the working pressure of said generator, said last mentioned means being adjusted to give, for values of said working pressure below a predetermined limit value, final compression pressures in said power cylinder lower than those necessary to achieve, in said power cylinder, self ignition of the fuel therein under normal conditions, and means responsive to variation of the working pressure of said generator for admixing, for low values of said working pressure, compressed air from said casing with the air admitted from the atmosphere into said compressor cylinder during the suction stroke of said compressor piston.

3. An internal combustion operated free piston gas generator which comprises, in combination, a power cylinder, an air compressor cylinder, a power piston for cooperating with said power cylinder, a compressor piston for cooperating with said compressor cylinder, said two pistons being rigid with each other, means controlled by said power piston for feeding compressed air from said compressor cylinder to said power cylinder at the end of the suction stroke of said power piston, means for automatically controlling the final compression pressure in said power cylinder in response to variation of the working pressure of said generator, said last mentioned means

being adjusted to give, for values of said working pressure below a predetermined limit value, final compression pressures in said power cylinder lower than those necessary to achieve, in said power cylinder, self ignition of the fuel therein under normal conditions, and means responsive to variation of the working pressure of said generator for admixing, for low values of said working pressure, compressed air directly from said compressor cylinder with the air admitted from the atmosphere into said compressor cylinder during the suction stroke of said compressor piston.

4. A power plant which comprises, in combination, an internal combustion operated free piston gas generator including a power cylinder, an air compressor cylinder, a power piston for cooperating with said power cylinder, a compressor piston for cooperating with said compressor cylinder, said two pistons being rigid with each other, means controlled by said power piston for feeding compressed air from said compressor cylinder to said power cylinder at the end of the suction stroke of said power piston, a receiver machine operated by power gases supplied from said power cylinder, means for automatically controlling the final compression pressure in said power cylinder in response to variation of the load of said receiver, said last mentioned means being adjusted to give, for values of said load below a predetermined limit value, final compression pressures in said power cylinder lower than those necessary to achieve, in said power cylinder, self ignition of the fuel therein under normal conditions, and means responsive to variation of the load of said receiver for admixing, for low values of said load, compressed air from said compressor cylinder with the air admitted from the atmosphere into said compressor cylinder during the suction stroke of said compressor piston.

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