FREE PISTON MACHINE

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Fig.1.

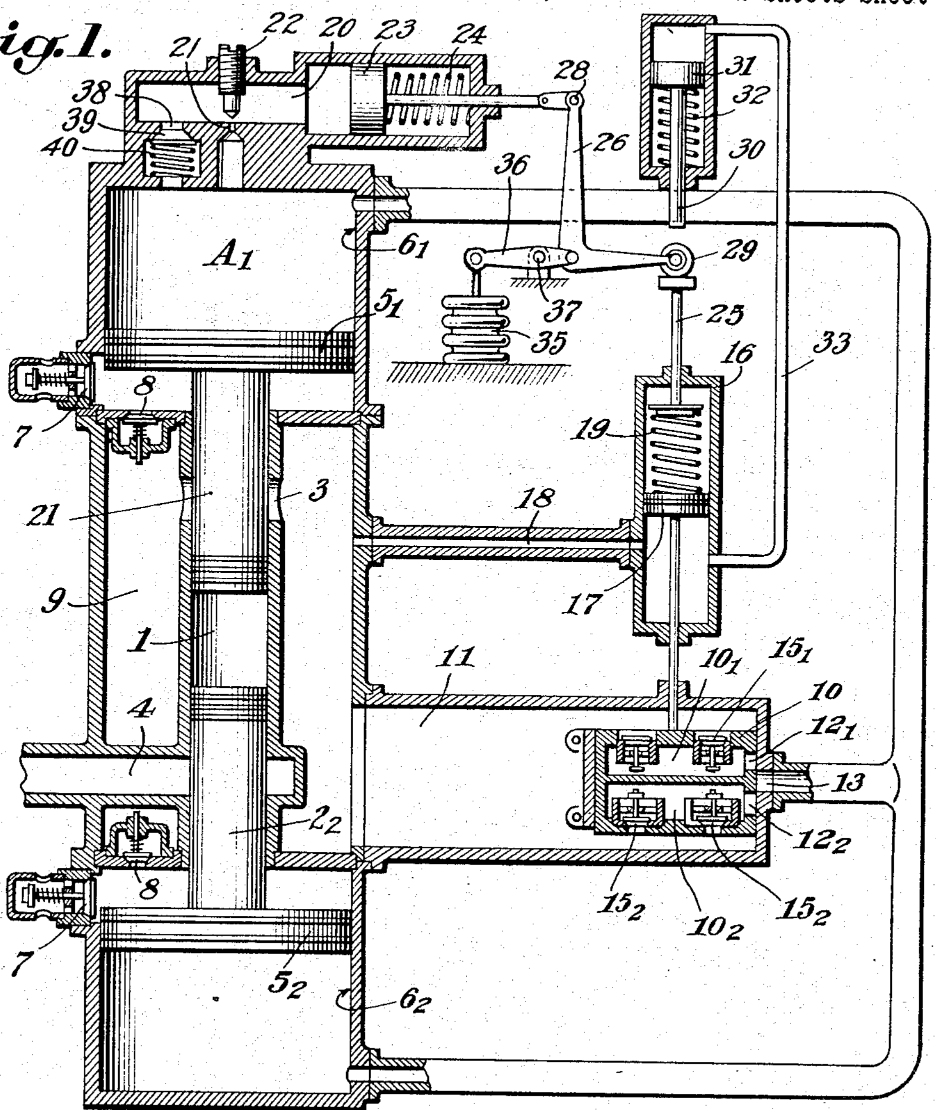
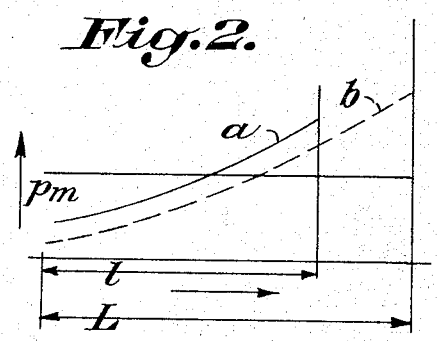


Fig.2.



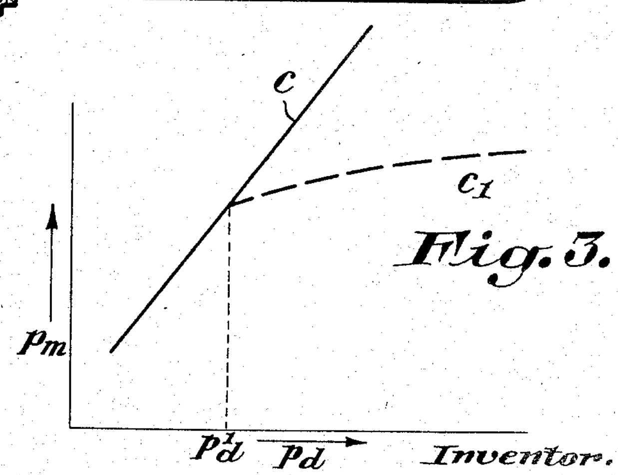


Fig.3.

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FREE PISTON MACHINE

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Fig. 5.

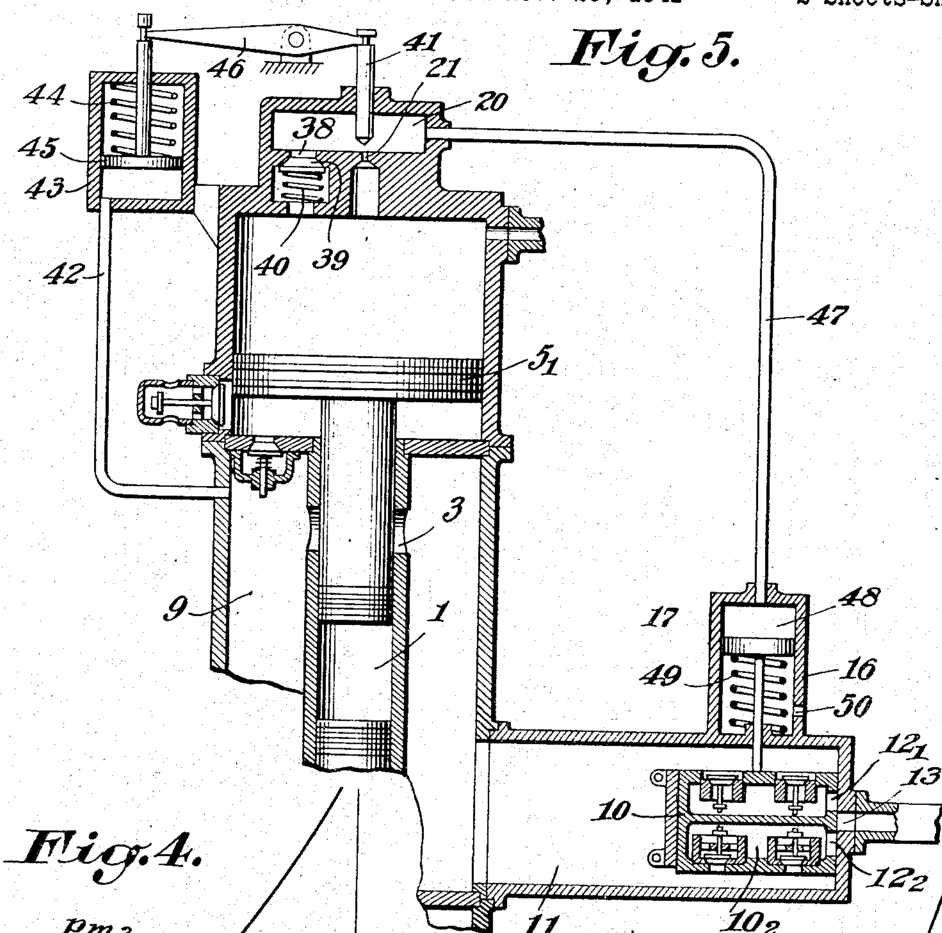


Fig. 4.

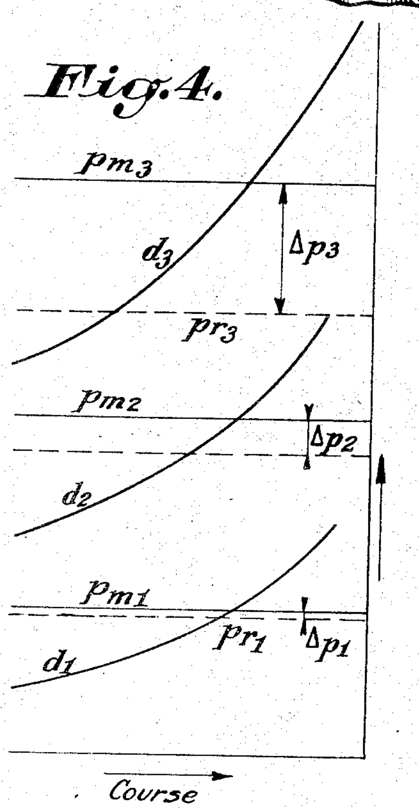
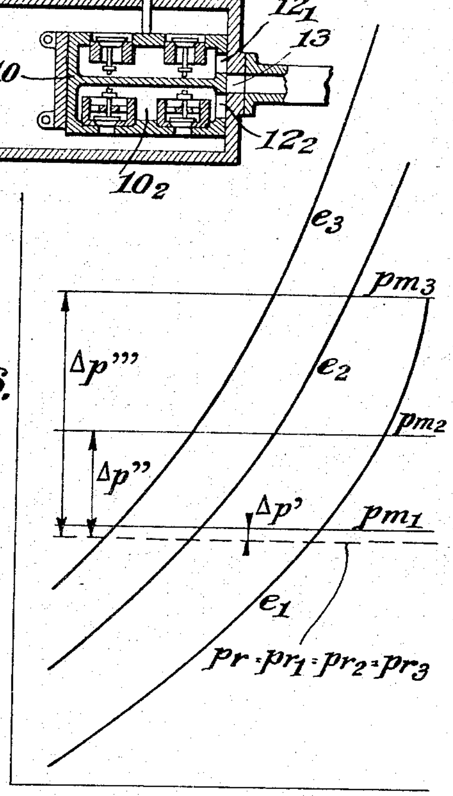


Fig. 6.



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Patented Aug. 15, 1944 2,355,924

UNITED STATES PATENT OFFICE

2,355,924

FREE PISTON MACHINE

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Application November 25, 1941, Serial No. 420,433
In France September 3, 1941

9 Claims. (Cl. 230—56)

The present invention relates to free piston machines, that is to say machines for the production of gas under pressure including one or several reciprocating elements the length of stroke of which can vary freely within certain limits, contrary to what takes place, for instance, in machines including connecting rods and crankshafts.

The invention is more especially, although not exclusively, concerned, among these machines, with those in which the discharge pressure is variable, and in particular those in which, furthermore, at least a portion of the compression work takes place during the return stroke of the reciprocating elements. And it is still more especially concerned with the "auto-generators" of this kind, the expression "auto-generator" designating a free piston machine in which at least a portion of the air fed by the compressor part of the machine serves the scavenging and the feed of the motor part of the same, the mixture of burnt gases and excess of scavenging air being sent to an expansion receiver, such for instance as a turbine.

The object of the present invention is to provide a machine of this kind which is better adapted to meet the requirements of practice than those used for the same purpose up to the present time.

According to an essential feature of the present invention, the machine is provided with a pneumatic energy accumulator capable of giving back to the reciprocating element or elements, during the return stroke thereof, energy stored up during the outward strokes, the energy brought into play in the pneumatic accumulator or accumulators being automatically varied by means of a source of gas under pressure controlled by a device operating as a function of at least one characteristic of operation of the machine, and, furthermore, this control device is influenced, on the one hand, by variations of the pressure existing in the accumulator or accumulators for a given position of the reciprocating element or elements and, on the other hand, by variations of the length of the stroke of said element or elements.

According to another feature of the invention, the control device, or the means for regulating it, is arranged in such manner that the law according to which this device operates in response to variations of the discharge pressure, or of a pressure varying in accordance with this discharge pressure, is a non-linear law.

According to still another feature of the invention, means are provided for varying the energy which produces the return of the reciprocating element or elements in accordance with the altitude at which the machine is working.

Other features of the present invention will result from the following detailed description of some specific embodiments thereof.

Preferred embodiments of the present invention will be hereinafter described, with reference to the accompanying drawings, given merely by way of example, and in which:

Fig. 1 is a diagrammatical view of a free piston machine made according to an embodiment of the invention;

Figs. 2, 3 and 4 are diagrams for illustrating the operation of a machine according to the invention;

Fig. 5 is a view, similar to Fig. 1, of a free piston machine made according to a second embodiment of the invention;

Fig. 6 is a diagram for facilitating a good understanding of the operation of the machine according to Fig. 5.

In the following description, it will be supposed that the machine that is being considered is of the free piston type and constitutes a variable discharge pressure auto-generator in which at least a portion of the compression work is produced during the return strokes.

Concerning the general construction of the machine, it is of any suitable type and for instance it includes the following parts:

a. A cylinder 1, constituting the motor cylinder and in which are mounted two pistons 2^1 and 2^2 adapted to cooperate, respectively, when they are close to the outer ends of their strokes, with an inlet port 3 and an outlet port 4;

b. Two compressor pistons 5^1 and 5^2, radially slidable in cylinders 6^1 and 6^2, respectively, are rigid with the motor pistons, and the inner faces of said compressor pistons ensure, owing to the provision of inlet valves 7 and outlet valves 8, the feed of air under pressure to a fluidtight case 9 which surrounds the motor cylinder 1;

c. Between these motor pistons, there is provided a synchronizing mechanism, of the type shown in my Patent Number 2,075,133, and consists, for instance, of a system of levers oscillating about a fixed axis and having their opposed ends interrelated, by means of connecting rods, with the two reciprocating elements moving in opposed directions;

d. Accumulators are provided for accumulating, during the outward strokes of the pistons, an amount of energy to be given back to said pistons during the compression strokes, which are the return or inward strokes thereof, and these energy accumulators are constituted, for instance, by causing the outer faces of pistons 5^1 and 5^2 to cooperate with the end portions of cylinders 6^1 and 6^2. These accumulators are designated, in the following description, by letters A^1 and A^2, respectively;

e. In order to obtain, as it will be hereinafter more fully described, that the energy brought into play in accumulators A^1 and A^2 may vary in accordance with the discharge pressure of the machine, I provide an intermittent communication between said accumulators and a source of air under pressure or a discharge chamber, according as the amount of air present in the accumulators is too great or too small.

In particular, and as it will be hereinafter supposed, I utilize, as source of air under pressure and also as discharge chamber, a space in which the existing pressure is a characteristic of the machine. For instance, I make use of casing **9**, in which there is a pressure substantially equal to the discharge pressure (in the following description, I will designate, for simplification purposes, the pressure in said casing **9** by the expression "discharge pressure").

In this case, I interpose, between pneumatic accumulators A^1 and A^2 and casing **9**, a distributing system such that, on the one hand, when the working conditions are stable, it maintains these accumulators separated from said casing, and, on the other hand, when there is a variation of the working conditions, said system enables air contained in casing **9** to pass into the accumulators, or inversely.

This distributing system is constituted by a kind of slide valve **10**, mounted in a reservoir **11** which is constantly in communication with casing **9**, this slide valve including two chambers or compartments 10^1 and 10^2, respectively provided with ports 12^1 and 12^2 adapted, when either of them is brought opposite a fixed port **13**, to connect the corresponding compartment with conduits 14^1, 14^2 leading to accumulators A^1 and A^2, orifice **13** being closed when slide-valve **10** is in neutral position (position shown by Fig. 1).

I provide, in the walls of compartments 10^1 and 10^2, respectively, check valves 15^1 which permit only of air passing from compartment 10^1 into reservoir **11** and casing **9** and check valves 15^2 which permit only of air passing from reservoir **11** and casing **9** into chamber 10^2.

I provide means for coupling this distributing device to the movable element, for instance the piston, of a system including cylinder **16** and piston **17**, one of the faces of this piston being subjected to the discharge pressure, through a conduit **18**, while its other face is subjected to the action of a spring **19**. The whole is arranged in such manner that an increase of the discharge pressure produces a displacement of the slide valve such that orifice 12^2 comes opposite orifice **13**, and that, inversely, a reduction of this pressure causes orifice 12^1 to come opposite said orifice **13**.

Concerning the correcting or controlling means which are to ensure the return of distributor **10** into neutral position, after each variation of the working conditions, said correcting means are operated, according to a feature of the invention, both in accordance with the pressure existing, for a given position of the piston, in the pneumatic accumulator or accumulators and in accordance with the length of the piston stroke. For this purpose, preferably, I make use of the mean pressure in the accumulator or accumulators, or of a pressure the value of which depends upon said mean pressure, this last mentioned pressure being also variable in accordance with the length of stroke of the accumulator piston, as well as in accordance with the initial accumulator pressure.

In the embodiment of the invention illustrated by Fig. 1, I utilize, as controlling factor, the pressure p^c existing in a space **20** which is in communication with the inside of accumulator A^1 through a calibrated aperture **21**, preferably adjustable by means of a needle valve **22**.

Preferably, I make use of the pressure existing in space **20** for adjusting the tension of spring **19** which brings back distributing member **10** into position. Consequently, this pressure is caused to act on a piston **23** which is acted upon by a spring **24**. This piston acts, through a transmission the detail of which will be hereinafter more fully described, upon a push-piece **25** against which spring **19** is bearing. The whole is arranged in such manner that an increase of pressure in space **20** corresponds to an increase of the tension of spring **19**.

An auto-generator made as above described will work in the following manner:

Supposing that the discharge pressure passes from a value p^1, for which distributor **10** was in neutral position, to a higher value p^2, piston **17** is displaced against the action of spring **19** and orifice 12^2 is brought opposite orifice **13**. Air under pressure present in casing **9** can then, during the portion of the stroke for which the discharge pressure is higher than the pressure in the accumulators, flow past check valves 15^2 and come, through conduits 14^1 and 14^2 into said accumulators, where it increases the mass of air present therein. If, on the contrary, the discharge pressure had decreased, distributing member **10** would have been displaced in the opposite direction and orifice 12^1 would come opposite orifice **13**, thus permitting a portion of the air present in the accumulators to return into casing **9** through check valves 15^1, during the portions of the piston strokes for which the pressure in said accumulators is higher than the pressure in said casing.

The return of distributing member **10** into its neutral position, in which orifice **13** cannot communicate either with 12^1 and with 12^2, is obtained by the variation of the pressure conditions in the accumulators, which variation produces a modification of the pressure existing in space **20**, and, consequently, a variation of the tension of spring **19**.

Supposing that the communication between accumulator A^1 and space **20** is obtained only through one or several calibrated orifices such as **21**, the pressure existing in space **20** is substantially equal to the mean pressure in accumulator A^1.

The diagram of Fig. 2 shows how the pressure conditions in the accumulators are influenced by the utilization, as factor for controlling the working of the device, of the mean pressure in said accumulators.

In this diagram, solid line a represents for a given stable state of conditions, corresponding to a given pressure of discharge of the machine, the variation of the pressure in the accumulator when the stroke length l of the reciprocating element is relatively short, the mean pressure which corresponds to this curve of variation being equal to p_m.

If, at a given time, the length of stroke of the reciprocating system passes from value l to a higher value L, without any variation of the discharge pressure of the machine, this increase first causes the mean pressure to pass to a higher value. This increased mean pressure, acting on piston **23**, destroys the state of equilibrium of system **10—17** and causes distributing member **10** to move in such manner that a portion of the air present in the accumulators passes into casing **9** through check valves 15^1. The increase of the length of stroke therefore influences the control device in the same manner as a decrease of the discharge pressure of the machine would have done.

The equilibrium will be restored and, consequently, device 10—17 will return into its neutral position when, for longer strokes of the pistons, the pressure variation in the accumulator will correspond to the dotted line b of Fig. 2, the mean pressure which corresponds to this curve being again equal to p_m.

Although the machine can work satisfactorily with the arrangement just above described, it seems advantageous to make use of the following supplementary features, which may eventually be used separately.

According to one of these supplementary features, the control device 10—17 is arranged in such manner as to work, in response to variations of the discharge pressure existing in casing 9, according to a non-linear law.

For this purpose, according to the embodiment illustrated by Fig. 1, I act on the transmission interposed between piston 23 and push-piece 25.

In this embodiment of the invention, this transmission is provided with a bell-crank lever 26 adapted to pivot about an axis 27, one of the ends of said lever being coupled at 28 with piston 23, while the other end 29 thereof acts on push-piece 25.

If this lever were utilized alone, the control device would work in accordance with a law corresponding to the straight line c of Fig. 3 of the drawings, in which the abscissas represent the discharge pressure p_d of the auto-generator, while the ordinates represent the pressures p_m in the accumulator.

In order to obtain a non-linear characteristic curve, for instance a curve in the form of a broken line, I proceed as follows:

I provide, above the end 29 of lever 26, a push piece 30, rigid with a piston 31 which is subjected, on one side thereof, to the action of a spring 32, and, on the other side, to the pressure existing in casing 9, this pressure being fed through a conduit 33 to the upper part of a cylinder 34 inside which piston 31 is movable. As long as the discharge pressure of the auto-generator has not reached a value equal to

$$p_d^1$$

spring 32 keeps push piece 30 away from the end 29 of lever 26, but once the discharge pressure

$$p_d^1$$

has been reached, the push-piece bears against said end of lever 26 and this with a force which is the greater as the discharge pressure is higher.

Consequently, when the discharge pressure has a value lower than

$$p_d^1$$

the operation of the control device corresponds to line c, but once this value of the discharged pressure has been exceeded, the working of the control device corresponds to line c^1, the inclination of which is smaller than that of line c.

When the auto-generator is mounted on a vehicle, for instance an aircraft, intended to work at different altitudes, it is useful, according to another feature of the present invention, to provide a supplementary control element which influences control device 10—17 in accordance with the value of the altitude.

In order to obtain this result, I have, in the embodiment shown by Fig. 1, provided a barometric box system 35 adapted to pivot a lever 36 about an axis 37, the end of this lever which is opposed to that connected to said barometric system carrying the axis 27 of bell crank lever 26.

This barometric correcting device is arranged in such a manner that the energy of the accumulators decreases when the altitude increases.

According to still another feature of the invention, I provide means whereby the pressure existing in space 20 is different from the mean pressure in accumulator A^1, while remaining still dependent upon both the initial pressure in the accumulator and the length of stroke of the reciprocating elements. Owing to this feature, I obtain a modification of the law according to which the return energy varies as a function of the length of stroke.

For this purpose, I provide, in order to connect accumulator A^1 and space 20, in addition to calibrated orifice 21 and parallelly thereto, a kind of by-pass 38 controlled by a check valve 38 subjected to the action of a spring 40. According to the direction in which check valve 38 opens, the pressure in space 20 is lower or higher than the mean pressure of the accumulator. In the embodiments of the invention illustrated by Figs. 1 and 5, this check valve is arranged in such manner that it permits a portion of the air under pressure present in space 20 to escape into accumulator A^1, when the pressure in said accumulator is lower than that existing in said space 20, while this check-valve prevents passage of air from accumulator A^1 into space 20 through said by-pass. Consequently, the pressure in this space 20 is lower than the mean pressure in accumulator A^1.

The action of by-pass 38 results from the diagram of Fig. 4. In this diagram the three curves d^1, d^2, d^3 represent the variation of the pressure in the accumulator. The horizontal lines p_{m_1}, p_{m_2}, p_{m_3} are the mean pressures corresponding respectively to these three curves. Finally, the horizontal lines p_{r_1}, p_{r_2}, p_{r_3} are the pressures existing in space 20. These last mentioned pressures are lower than the corresponding mean pressures p_{m_1}, p_{m_2}, p_{m_3}, with respective differences equal to Δp_1, Δp_2, Δp_3, these differences being due to the provision of the by-pass and the check valve interposed between the accumulator and space 20.

If the tension of spring 40 is invariable, the value Δp is a function of

$$\frac{S_1}{S_2}$$

S_1 being the area of calibrated orifice 21 and S_2 the area of the check valve 39.

In order to determine this value Δp, I may act either on the area of the passage through calibrated orifice 21 by means of a needle valve 22, or on the tension of the spring 40 of check valve 39. This adjustment may be effected automatically in accordance with an operating factor of the machine, the latter including at least one generator of gas under pressure and at least one receiver machine, for instance a turbine.

This factor may advantageously consist in one of the working pressures of the generator.

According to still another feature of my invention, the pressure p_r in space 20 is regulated as a function of the working pressure of the generator in such manner that, under stable working conditions, this pressure is always of the same value. The difference Δp between the mean pressure in the accumulator and pressure p_r must therefore increase as a function of the working pressure in such manner that this result is obtained.

The diagram of Fig. 6 shows, for three different working pressure conditions of accumulator A_1, corresponding to three different feed pressures of the auto-generator:

a. The curves e_1, e_2, e_3 of the pressure in the accumulator as a function of the length of stroke, for these three working conditions:

b. The horizontal lines giving the mean pressures in the accumulator corresponding respectively to these three curves;

c. The horizontal dotted line giving the value of pressure p_r, p_{r1}, p_{r2}, p_{r3} in space **20**, which remains the same for the three working conditions that are being considered, the difference between p_{m_1} and p_r being equal to $\Delta p'$; while that between p_{m_2} and p_r is $\Delta p''$ and that between p_{m_3} and p_r is $\Delta p'''$.

A machine working in accordance with the conditions illustrated by the diagram of Fig. 6 is shown by Fig. 5.

In this embodiment of my invention, the area of the cross section of calibrated orifice **21** is varied by means of a needle valve **41** the position of which is variable in accordance with the value of the working pressure or discharge pressure in casing **9**.

In order to obtain the desired working of this needle valve, this casing is connected, through a casing **42**, with a cylinder **43** in which can move, against the action of a spring **44**, a piston **45** the rod of which is operatively connected to one of the ends of a pivoting lever **46** the other end of which is connected with needle valve **41**.

It results from Fig. 5 that the area of orifice **21** is the smaller as the working pressure of the generator increases. Consequently, the difference Δp further increases when said working pressure increases, being then consequently greater than in the case of Fig. 4, in which the cross section of aperture **21** remains constant.

The shape and size of the element which varies the cross section through orifice **21**, and the force of spring **44** are chosen in such manner that the differences $\Delta p'$, $\Delta p''$ and $\Delta p'''$ that are obtained are those illustrated by Fig. 6.

The fact that the same regulating pressure p_r is maintained in space **20** whenever the working conditions of the machine are stable and irrespective of the value of the mean pressure p_m in the accumulator, permits of obtaining an important simplification of the device which controls the value of the pressures in the accumulators. As a matter of fact, as shown by Fig. 5, the pressure p_r existing in space **20** can then be caused to act directly on the piston **17** of distributing device **10**, without interposing mechanical means. It suffices to connect space **20**, through a conduit **47**, with the space **48** inside cylinder **16** and above piston **17** and to subject the lower side of said piston to the action of a spring **49**, the portion of cylinder **16** in which this spring is housed being provided with an orifice **50** which connects this portion of the cylinder with the atmosphere.

The device of Fig. 5 will work in the following manner:

Supposing that the discharge pressure of the generator, and therefore the pressure in casing **9**, increases, this increase produces a displacement of needle valve **41** in the direction which reduces the section of flow through calibrated orifice **21**. Consequently, the pressure in space **20** drops, which causes distributing member **10** to move in such manner that the orifice **12**[2] thereof is brought opposite orifice **13**, so as to permit air under pressure present in casing **9** to pass into the accumulators. Consequently, the initial pressure, and also the mean pressure in said accumulators increases and reaches the value which corresponds to the new working pressure of the generator. Once these new pressure conditions have become stabilized, the pressure p_r in space **20** has returned to its initial value since, due to the increase of the pressure in casing **9**, the section of flow through orifice **21** is now smaller than precedingly. In view of the fact that the pressure in space **20** has come back to its former value, distributing member **10** has come back into the neutral position shown by Fig. 5, whereby the whole is again ready to operate for a new variation of the working pressure.

Of course, when the working pressure in casing **9** decreases, the operations above described take place in the opposite direction.

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

What I claim is:

1. A free piston machine of the type described which comprises, in combination, a motor cylinder and a compressor cylinder, at least one reciprocating structure movable in the axial direction of said cylinders, including a motor piston and a compressor piston rigid with each other and adapted to cooperate with said motor cylinder and said compressor cylinder, respectively, a pneumatic accumulator associated with said reciprocating structure for storing up energy during the outstrokes of the pistons and giving back said energy to said structure during the return strokes thereof, a source of gas under pressure, control means, responsive to variations of at least one working factor of the machine, for producing an interchange of gas between said accumulator and said source when such variations occur, and means responsive both to variations of the pressure existing in said accumulator for a given position of said reciprocating structure and to the length of stroke of said structure, for regulating said control means.

2. A free piston machine of the type described which comprises, in combination, a motor cylinder and a compressor cylinder, at least one reciprocating structure movable in the axial direction of said cylinders, including a motor piston and a compressor piston rigid with each other and adapted to cooperate with said motor cylinder and said compressor cylinder, respectively, a pneumatic accumulator associated with said reciprocating structure for storing up energy during the outstrokes of the pistons and giving back said energy to said structure during the return strokes thereof, a chamber containing gas under pressure, control means responsive to variations of the discharge pressure from said compressor cylinder, for producing an interchange of gas between said accumulator and said chamber when such variations occur, and means responsive both to variations of the pressure existing in said accumulator for a given position of said reciprocating structure and to

variations of stroke of the reciprocating movement of said structure, for regulating said control means.

3. A free piston machine of the type described, which comprises, in combination, a motor cylinder and a compressor cylinder, at least one reciprocating structure movable in the axial direction of said cylinders, including a motor piston and a compressor piston rigid with each other and adapted to cooperate with said motor cylinder and said compressor cylinder, respectively, a pneumatic accumulator associated with said reciprocating structure for storing up energy during the outstrokes of the pistons and giving back said energy to said structure during the return strokes thereof, a casing arranged to receive the compressed gas from said compressor cylinder, control means responsive to variations of the pressure in said casing, for producing an interchange of gas between said casing and said accumulator when such variations occur, and means for returning said control means into neutral position, said return means being responsive both to variations of the pressure existing in said accumulator for a given position of said reciprocating structure and to variations of the stroke of the movement of said structure.

4. A free piston machine of the type described, which comprises, in combination, a motor cylinder and a compressor cylinder, at least one reciprocating structure movable in the axial direction of said cylinders, including a motor piston and a compressor piston rigid with each other and adapted to cooperate with said motor cylinder and said compressor cylinder, respectively, a pneumatic accumulator associated with said reciprocating structure for storing up energy during the outstrokes of the pistons and giving back said energy to said structure during the return strokes thereof, a casing arranged to receive the compressed gas from said compressor cylinder, control means responsive to variations of the pressure in said casing, for producing an interchange of gas between said casing and said accumulator when such variations occur, and means for returning said control means into neutral position, said return means being responsive to variations of the pressure existing in said accumulator for a given position of said reciprocating structure, to variations of the stroke of the reciprocating movement of said structure, and also to variations of the atmosmospheric pressure.

5. A free piston machine of the type described, which comprises, in combination, a motor cylinder and a compressor cylinder, at least one reciprocating structure movable in the axial direction of said cylinders, including a motor piston and a compressor piston rigid with each other and adapted to cooperate with said motor cylinder and said compressor cylinder, respectively, a pneumatic accumulator associated with said reciprocating structure for storing up energy during the outstrokes of the pistons and giving back said energy to said structure during the return strokes thereof, a casing arranged to receive the compressed gas from said compressor cylinder, control means responsive to variations of the pressure in said casing for producing an interchange of gas between said casing and said accumulator when such variations occur, and return means for bringing back said control means into neutral position, said return means being adjustable in response to variations of the mean pressure in said accumulator.

6. A free piston machine of the type described, which comprises, in combination, a motor cylinder and a compressor cylinder, at least one reciprocating structure movable in the axial direction of said cylinders, including a motor piston and a compressor piston rigid with each other and adapted to cooperate with said motor cylinder and said compressor cylinder, respectively, a pneumatic accumulator including a piston and a cylinder respectively rigid with the above mentioned pistons and cylinders, adapted to form, during the outstrokes of the reciprocating structure, a compressed gas cushion which produces the return strokes of the pistons, a casing adapted to receive the compressed gas from said compressor cylinder, control means responsive to variations of the pressure in said casing for interconnecting said casing and said accumulator in one direction or the other according as the pressure in said casing has increased or decreased, a chamber communicating with the inside of said accumulator through a small calibrated orifice, and means for elastically returning said control means into neutral position, said return means being responsive to variations of the pressure in said chamber.

7. A machine according to claim 6 further including a connection between said chamber and the inside of said accumulator adapted to bypass said calibrated orifice, said connection consisting of a conduit, a check valve in said conduit and elastic means for urging said check valve toward the closed position thereof.

8. A free piston machine of the type described, which comprises, in combination, a motor cylinder and a compressor cylinder, at least one reciprocating structure movable in the axial direction of said cylinder, including a motor piston and a compressor piston rigid with each other and adapted to cooperate with said motor cylinder and said compressor cylinder, respectively, a pneumatic accumulator including a piston and a cylinder respectively rigid with the above mentioned pistons and cylinders, adapted to form, during the outstrokes of the reciprocating structure, a compressed gas cushion which produces the return strokes of the pistons, a casing adapted to receive the compressed gas from said compressor cylinder, control means responsive to variations of the pressure in said casing for interconnecting said casing and said accumulator in one direction or the other according as the pressure in said casing has increased or decreased, a chamber communicating with the inside of said accumulator through a small calibrated orifice, means for returning said control means into neutral position, said return means being responsive to variations of the pressure in said chamber, and means operative by variations of the pressure on said casing for varying the section of flow through said calibrated orifice in accordance with said pressure in the casing.

9. A machine according to claim 8 in which the last mentioned means are adapted to keep the pressure in said chamber at the same value for all stable working conditions.

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