Aug. 8, 1939 R. PATERAS PESCARA 2,168,829

FREE PISTON MACHINE

Filed July 14, 1937 2 Sheets-Sheet 1

Fig. 1.

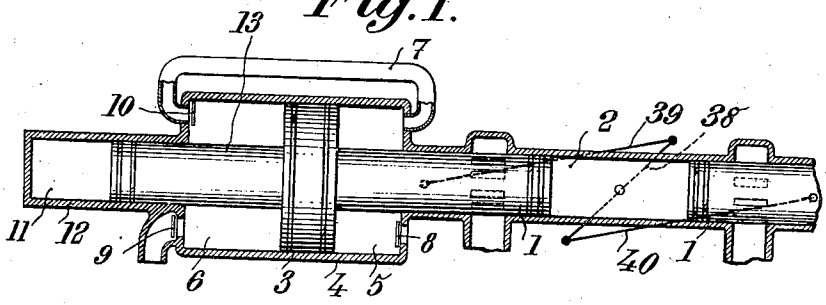


Fig. 2.

Fig. 3.

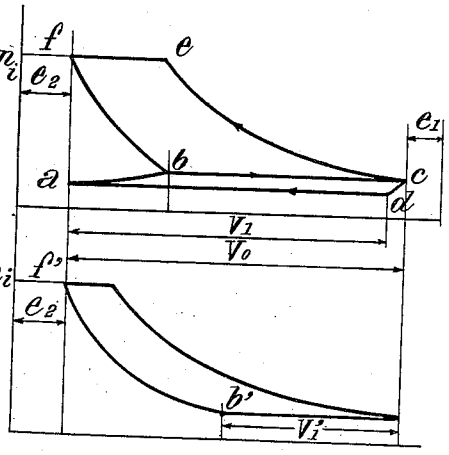
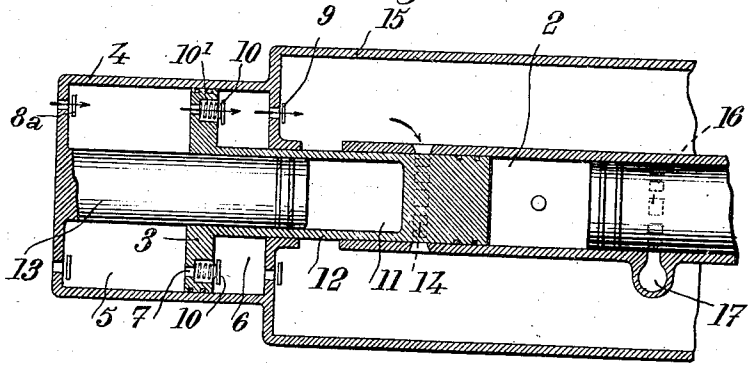


Fig. 4.



Inventor:
Raul Pateras Pescara,

Bailey & Carson
Attorneys

Aug. 8, 1939 R. PATERAS PESCARA 2,168,829

FREE PISTON MACHINE

Filed July 14, 1937 2 Sheets-Sheet 2

Fig. 5.

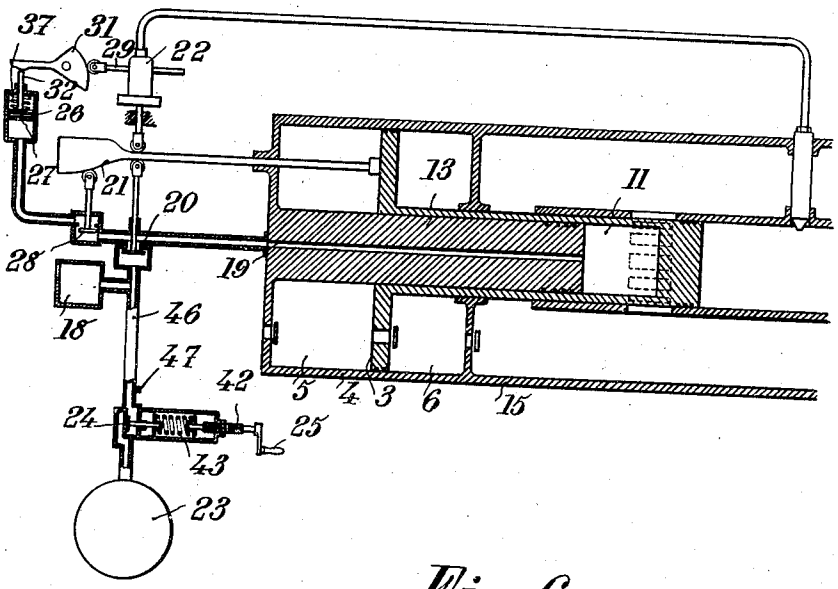
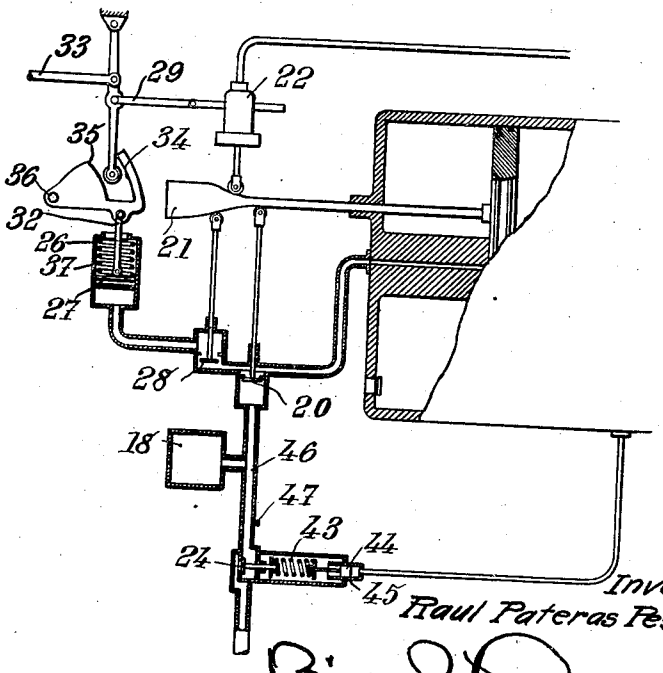


Fig. 6.



Inventor:
Raul Pateras Pescara,
Bailey & Carson
Attorneys

Patented Aug. 8, 1939 2,168,829

UNITED STATES PATENT OFFICE

2,168,829

FREE PISTON MACHINE

Raul Pateras Pescara, Paris, France

Application July 14, 1937, Serial No. 153,648
In France July 17, 1936

17 Claims. (Cl. 230—56)

The present invention relates to free piston machines at least a portion of the power of which is employed to compress a gas. It is more especially, although not exclusively, concerned with free piston self generating machines, that is to say machines of the type above referred to in which at least a portion of the compressed gas is utilized for the feed and the scavenging of the engine cylinder.

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 machines of the same kind used prior to the present invention.

The essential feature of the invention consists, while devising the machines in question in such manner that compression takes place in at least two stages, in dimensioning said machines in such manner that the compression ratio of the first stage is sufficiently low in order that the volumetric ratio of said stage, and therefore the volumetric ratio of the whole of the machine may have a value which is high and little variable when the discharge pressure of the machine varies.

Another feature of the invention, relating more especially to auto-generating machines of the kind above referred to, consists in devising the elements of the machine in such manner that the path of the gases during their compression and until they enter the engine cylinder is in a single direction, as short as possible and preferably substantially parallel to the axis of the machine.

A third feature of the present invention, which relates more especially although not exclusively to machines of the type above referred to working with variable pressures and in which most of the compression work takes place during the return strokes of the reciprocating elements, consists, while making use, for ensuring the return strokes of said reciprocating elements, of variable feed pressure pneumatic accumulators, in providing means for proportioning, at least approximately, the quantity of fuel introduced into the engine cylinders, or at least the limits within which this quantity can be varied for each working pressure, to the feed pressure of said accumulators or to any pressure proportional to the latter.

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 showing, in partial longitudinal section, a motor-compressor of the free piston type made according to the present invention;

Figs. 2 and 3 are diagrams showing curves relating to the operation of a motor-compressor made according to the present invention and of an ordinary motor compressor, respectively;

Fig. 4 is a diagrammatical view showing, in partial longitudinal section, an auto-generator with free pistons made according to the invention;

Fig. 5 is a diagrammatical view showing, in partial longitudinal section, an auto-generator of the free piston type embodying another feature of the invention;

Fig. 6 is a view analogous to Fig. 5, showing a modification.

According to the present invention, the motor compressor is devised in such manner that compression takes place in several stages, for instance, as it will be supposed in the following description, in two stages, which will be respectively called "pre-compression stage", and "compression stage".

According to the essential feature of the invention, instead of endeavouring to obtain, in each of said stages, rates of compression which are substantially equal, as it is generally done, I determine the various characteristics of the machine in such manner (especially the clearance spaces and the bores of the cylinders) that the ratio of compression of the pre-compression stage is sufficiently low in order that the volumetric efficiency of said stage and consequently that of the whole of the machine may reach a value which is high and little variable when the discharge pressure of the compression stage is varied.

The volumetric ratio of a compressor is characterized, in a general manner, by the ratio

$$\frac{V_1}{V_0}$$

of the suction stroke of its reciprocating elements and of the total stroke.

From a practical point of view, it is therefore advantageous to increase the volumetric efficiency of a compressor if it is desired to reduce its weight and its volume for a given output, that is to say to increase its power per unit of weight.

In the case of compressors including a crankshaft, it has been possible to increase their volumetric efficiency by considerably reducing the clearance space, a thing which is not possible with motor-compressors of the free piston type, because the clearance spaces of these last mentioned compressors are relatively important and their variations of output are determined by variations of the discharge stroke.

It is known that the length of the suction stroke V_1 is the smaller as the volume of the clearance space and the discharge pressure are greater. It will be readily understood, then, that, if steps are taken as just above explained for effecting, in a motor-compressor of the free piston type, a pre-compression of sufficiently low ratio, it is possible, while keeping clearance spaces of volumes ensuring a good working of these machines, to obtain suction strokes V_1 which approximate the total strokes V_0, since the mass of air imprisoned at low pressure in said clearance spaces is quickly expanded.

Although it is possible to consider making the pre-compression and the compression above referred to in distinct vessels, it seems that it is more advantageous, for reasons of construction, to make both operations in the same cylinder, on either side of a compressor piston, working on the double action principle in said cylinder.

For this purpose, it is advantageous to have recourse to the arrangement disclosed by Fig. 1 of the drawings.

In this case, the motor-compressor is essentially provided with two motor pistons **1**, synchronized in any suitable manner, for instance by a lever **38** connected to the ends of two connecting rods **39** and **40**, these pistons moving in a common cylinder **2**. These pistons **1** are each rigid with a compressor piston **3** moving in a distinct cylinder **4**. Precompression and compression take place respectively in the chambers of variable volume **5** and **6** located on either side of said compressor piston **3**, which then works on the double action principle in said cylinder **4**, said chambers being for instance connected together by a conduit **7**.

I provide the pre-compression chamber **5** with at least one intake valve **8**. The compression chamber **6** is fitted with at least one discharge valve **9**. Between the two chambers, for instance at the outlet of conduit **7** into chamber **6**, I provide a valve **10**.

Finally, in order to form compensating cushions **11**, I provide systems of a cylinder **12** and a piston **13** one of the elements of which, for instance piston **13** is rigid with the movable parts, to wit pistons **1** and **3**, and the other element consisting of an extension of the end of cylinder **4**.

The diagram of Fig. 2 permits if understanding the operation of the motor-compressor thus established and the diagram of Fig. 3 permits of comparing its operation to that of an ordinary compressor, of the same stroke compressing air to the same final pressure pi.

On the diagram of Fig. 2, *a, b, c, d* represents the pre-compression cycle and *c, e, f, b* the compression cycle. It will be understood that, if the pre-compression ratio is relatively low, the curve *c, d* which represents the expansion of the air imprisoned is clearance space e^1 existing, at the end of the pre-compression stroke, at the end of chamber **5** is of small length and of a shape which varies but little when the final pressure pi varies. It follows that the length of the suction stroke V_1 and therefore the volumetric efficiency

$$\frac{V_1}{V_0}$$

will also vary but little when said final pressure pi varies, the variations of the latter producing chiefly, in said curve, a modification of the expansion curve *f b* corresponding to the expansion of the air imprisoned in the clearance space e_2 remaining at the end of the compression operation in chamber **6**.

The diagram of Fig. 3 shows that, for the same final pressure pi, the suction stroke V_1 of the ordinary compressor is much smaller than the suction stroke V_1 of the compressor of the same geometrical stroke made according to the invention. It is further visible that the volumetric efficiency

$$\frac{V_1}{V_0}$$

of the ordinary compressor varies within wide limits when the curve *f' b'* representing the expansion of the air imprisoned at the end of the compression in the clearance space e_2 is disposed toward the right as a consequence of an increase of the discharge pressure pi.

Thus, by way of example, if it is desired to make a motor compressor for which the pressure pi would be equal to 5 kg., the clearance space e_2 is such that

$$\frac{e_2}{V_0}=0.20$$

and the volumetric efficiency is equal to 0.96, the pre-compression ratio must have a value of 1.45, and for this purpose, the clearance space e_1 will be determined in such manner that

$$\frac{e_1}{V_0}$$

is equal to 0.20.

If now it is desired to make, no longer a motor compressor of the free piston type, but an auto-generator of the same type, in which at least a portion of the compressed air is used for scavenging the engine cylinder, I proceed in the following manner:

Preferably, this machine is devised in accordance with the main feature of the invention so that the compression of air takes place in at least two stages the first of which has a ratio of compression which is relatively low, whereby, for the reasons above stated with reference to the motor-compressor, the volumetric efficiency of said machine is high and little variable when the final compression pressure varies, this last mentioned pressure varying as a function of the load of the receiving apparatus, especially turbines, cooperating with the auto-generator.

Furthermore, advantageously, according to another feature of the invention, which can be used independently of that above set forth, I devise the elements of the machine in such manner that the path of air through the stages of compression and until it enters the engine cylinder is in a single direction, as short as possible and preferably substantially parallel to the axis of said cylinder, so as to eliminate losses of power resulting from reversing of the direction of flow of air or to pressure drops in bent conduits and accordingly to improve the efficiency of the machine.

For this purpose, and for instance as shown by the drawing (Fig. 4) I provide, in the walls of the engine cylinder **2**, on the one hand intake

ports 14 capable, when uncovered by one of the engine pistons close to its outer end of its reciprocating motion, to connect the engine cylinder with the inside of a fluidtight casing 15 surrounding said cylinder 2. The compressed air is introduced into this casing as it will be more fully explained in the following description.

On the other hand, I provide in the walls of cylinder 2, exhaust ports, capable, when they are opened by the other driving piston, to connect the inside of cylinder 2 with an exhaust conduit 17.

The compressor cylinders 4 are arranged respectively at the ends of casing 15 and in each of said cylinders 4, the chamber adjacent to said casing 15 constitutes the compression chamber 6, the pre-compression chambers 5 being then located each at one end of the machine.

Finally I provide a relatively important number (in order to facilitate the circulation of air through the machine) of intake valves 8, which are fitted at the free end of cylinder 4, discharge valves 9 which are provided at the other end of said cylinder in such manner that they can connect chamber 6 with the inside of casing 15, and finally valves 10 adapted to cooperate with respective conduits 7 which are provided in piston 3 so as to permit air to flow from chamber 5 to chamber 6 with a direct flow.

Preferably piston 13 is made rigid with the end of cylinder 4 and cylinder 12 is provided in the corresponding reciprocating structure, these parts being so dimensioned that the pneumatic accumulators 11 can store up a sufficient amount of energy, during the forward stroke of the movable elements, for ensuring, during the return stroke of said movable elements, the compression work in the engine cylinder and most of the air compression work in the compressor cylinders.

It should be noted that, according to such an arrangement, valves 10 have a tendency to be applied on their seats by inertia before the stopping of the reciprocating elements at the ends of their outward strokes. This drawback may be obviated either, as shown by Fig. 4, by placing said valves under the dependence of springs such as 10, which tend to keep them open, or by providing at the ends of cylinders 4 grooves capable, when they are uncovered by pistons 3, to establish a communication between chambers 5 and 6 close to the outer ends of the reciprocating displacements of said pistons.

An auto-generator made as above explained is such that air flows always in the same direction which is substantially parallel to the axis of the machine, which improves the general efficiency of said machine. Furthermore, the volumetric efficiency is high and varies but little when the discharge pressure varies, which enables said generator to be always capable of feeding receiving turbines, whatever be the load of said turbines.

By way of example, for an auto-generator having the characteristics above mentioned for a motor-compressor, the volumetric efficiency would vary only from 0.96 to 1 for variations of the scavenging pressure from 5 kg. to 1 kg., whereas the same pressure variations would produce variations of the volumetric efficiency from 0.54 to 1 for a generator in which the compression would be effected in the usual manner.

Although it is possible to proceed as above explained, I have found that it is preferable, when the compressed air that is produced is capable of scavenging and feeding the motor cylinder under variable pressures, which is the case with auto-generators, to have further recourse to another arrangement according to the invention which consists in arranging in such manner that the power accumulators 11 are of variable feed pressure.

Furthermore, I provide means permitting to proportion, at least approximately, the amount of fuel injected into the motor cylinder to said feed pressure.

It is thus possible to proportion the energy produced in the motor cylinder to the energy that said pneumatic accumulators must be capable of giving up, at the time of the return stroke of the movable elements, this last mentioned amount of energy being essentially variable since it depends not only upon the discharge stroke but also upon the discharge pressure, which varies when the machine is in operation.

For this purpose, it is advantageous to have recourse to one of the embodiments of the invention illustrated by Figs. 5 and 6.

I connect each pneumatic accumulator 11 with a chamber under pressure 18 through a conduit 19 partly provided in piston 13 and said accumulator is adapted to communicate with chamber 18 only during a portion (well determined) of the motion of the reciprocating elements, preferably close to the inner end of their reciprocating motion. For instance, I provide between said chamber 18 and said pneumatic accumulator 11 a valve 20 the opening of which is controlled by a cam 21 rigid with one of said reciprocating elements. Furthermore, advantageously, this cam ensures, by means of another inclined surface thereof, the operation of the feed pump 22.

Chamber 18 is fed with compressed air from a reservoir 23 containing air at a high pressure, for instance through an adjustable pressure relief device including a valve 24.

This device may be arranged, as shown by Fig. 5 in such manner that the workman can adjust at will the expansion ratio by means of an operating handle 25. The handle is connected to a screw 42 adapted to regulate the tension of a spring 43 tending to maintain the relief valve in a closed position.

Alternately, in the embodiment illustrated by Fig. 6, the pressure relief device is arranged in such manner that said expansion ratio is determined in an automatic manner, by a regulating device, advantageously as a function of the discharge pressure of the machine, said regulating device being then constituted, for instance, by a piston 44 slidable in a cylinder 45 and acting on the spring 43 so as to regulate its tension. The cylinder 45 communicates with the interior of casing 15 by a conduit 41. Preferably, the conduit 46 connecting the relief device with the valve 20 is provided with a constantly open leakage 47.

The system is devised in such manner that the variations of the feed pressure of accumulators 11, resulting from the operation of the pressure relief valve 24, ensure variations in the same direction of the amount of fuel injected into the motor cylinder.

For this purpose, for instance, I provide a system including a cylinder 26 and a piston 27, said cylinder being in communication with conduit 19, through a valve 28 which is advantageously adapted to be controlled by inclined face 21 ensuring the opening of valve 20.

The movable element of said cylinder-piston system (for instance piston 27) is caused to co-

act with the quantitative adjustment rod 29 of pump 22.

This can be effected either in a direct manner, as shown by Fig. 5, said rod being then controlled by a cam 31, itself controlled by the rod 32 of the piston.

Alternately, especially when rod 29 is already controlled by the rod 33 of a regulating device, the same result can be ensured through a correcting device which may consist, for instance as shown by Fig. 6, of two limiting inclined surfaces 34 and 35 pivoted about an axis 36 and controlled by said rod 32.

Advantageously, in both cases, a return spring 37 is provided for ensuring the displacements of the piston in the direction corresponding to a reduction of the amount of fuel that is injected.

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 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 appended claims.

What I claim is:

1. A free piston motor compressor unit comprising in combination, a motor cylinder, at least one motor piston adapted to slide freely in said motor cylinder, compression means comprising at least one compression cylinder and one compression piston operatively connected to said motor piston, said compression means forming a precompression chamber and a main compression chamber, the compression ratio in the precompression chamber being a fraction of the compression ratio in the main compression chamber, valve means for admitting air in the precompression chamber, one-way valve means for connecting the precompression chamber with the main compression chamber, said last valve means being operable by pressure in the precompression chamber to open communication with the main compression chamber and means for discharging the compressed air out of said main compression chamber.

2. A free piston motor compressor unit according to claim 1 wherein the compression stroke in the precompression chamber coincides with the inlet stroke in the main compression chamber, and the compression stroke in the main compression chamber coincides with the inlet stroke in the precompression chamber.

3. A free piston motor compressor unit of the type described comprising, in combination, a motor cylinder at least one compression cylinder, a piston adapted to slide freely in said motor cylinder, a second piston operatively connected to said first piston and adapted to slide in said compression cylinder, the piston sliding in said compression cylinder being double-acting and dividing said compression cylinder in two compressor chambers, valve means for admitting a gaseous fluid in the first of said chambers, one-way valve means for connecting said first chamber with the second chamber, and means for discharging the compressed fluid out of said second chamber, the compression ratio in said first chamber being lower than in said second chamber.

4. In a free piston motor compressor, a motor cylinder, a motor piston movable therein, a compression cylinder, a compression piston movable in said compression cylinder operatively connected to said motor piston, said compression piston dividing said compression cylinder into a precompression chamber and a compression chamber, one way valve means to admit air to the precompression chamber, one-way valve means for connecting said chambers to conduct air from the precompression chamber to the compression chamber, and means to discharge air from the compression chamber.

5. A free piston compressor unit comprising in combination a motor cylinder, at least one motor piston adapted to slide freely in said motor cylinder, compression means comprising at least one compression cylinder and one compression piston operatively connected to said first piston and adapted to slide in said compression cylinder, said compression piston dividing said compression cylinder into a main compression chamber and a precompression chamber, valve means for admitting a gaseous fluid into the precompression chamber, pipe means for connecting said precompression chamber and said compression chamber, said pipe means including a one-way valve adjacent the entrance of said compression chamber, and means for discharging compressed fluid out of the compression chamber.

6. A free piston compressor unit comprising in combination a motor cylinder, at least one motor piston adapted to slide freely in said motor cylinder, compression means comprising at least one compression cylinder and one compression piston operatively connected to said first piston and adapted to slide in said compression cylinder, said compression piston dividing said compression cylinder into a main compression chamber and a precompression chamber, valve means for admitting a gaseous fluid into the precompression chamber, means for conducting fluid from said precompression chamber to said compression chamber, means for discharging fluid out of said compression chamber, and means for conducting at least a part of said fluid to said motor cylinder, said cylinders and pistons being so arranged that the path of the gaseous fluid through said chambers and discharging means is substantially in a straight line.

7. A free piston compressor unit comprising in combination a motor cylinder, at least one motor piston adapted to slide freely in said motor cylinder, compression means comprising at least one compression cylinder aligned with said motor cylinder and one compression piston operatively connected to said first piston and adapted to slide in said compression cylinder, said compression piston dividing said compression cylinder into a main compression chamber on the same side of the compression piston as the motor piston and a precompression chamber on the opposite side thereof, valve means for admitting a gaseous fluid at the outer end of the precompression chamber, valve means in said compression piston for conducting fluid from said precompression chamber to said compression chamber, means for discharging fluid out of said compression chamber, and means for conducting at least a part of such fluid to said motor cylinder, said cylinders and pistons being so arranged that the path of the gaseous fluid through said chambers and discharging means is substantially in a straight line.

8. A system as claimed in claim 6 wherein said path is substantially parallel to the axis of the machine.

9. A free piston compressor unit comprising in combination a motor cylinder, at least one motor piston adapted to slide freely in said motor cylinder, means for returning said piston to its initial position at the end of the expansion stroke, com-

pression means comprising at least one compression cylinder and one compression piston operatively connected to said first piston and adapted to slide in said compression cylinder, said compression piston dividing said compression cylinder into a main compression chamber and a precompression chamber, valve means for admitting a gaseous fluid into the precompression chamber, means for connecting said precompression chamber and said compression chamber, a receiver surrounding said motor cylinder, means for discharging compressed fluid out of the compression chamber into said receiver, and means for conducting at least a portion of the air from the receiver to the engine.

10. A free piston compressor unit comprising in combination a motor cylinder, at least one motor piston adapted to slide freely in said motor cylinder, compression means comprising at least one compression cylinder and one compression piston operatively connected to said first piston and adapted to slide in said compression cylinder, said compression piston dividing said compression cylinder into a main compression chamber and a precompression chamber, valve means for admitting a gaseous fluid into the precompression chamber, valve means in said compression piston for connecting said precompression chamber and said compression chamber, and means for discharging compressed fluid out of the compression chamber.

11. In a device as claimed in claim 10 in which said compression piston causes compression in the precompression chamber on its outward stroke and in the compression chamber on its inward stroke, said valve opening into the compression chamber, and a spring acting on said valve in a direction to hold it open.

12. A free piston motor compressor unit of the type described comprising, in combination, a motor cylinder, at least one compression cylinder, a piston adapted to slide freely in said motor cylinder, a second piston connected to said first piston and adapted to slide in said compression cylinder, said second piston carrying out at least its main compression work on its inwardly directed stroke, means comprising at least supplementary cylinder and piston elements one rigidly connected to the first mentioned cylinders and the other carried by the free piston, the supplementary piston fitting slidably in the supplementary cylinder so as to form therewith a compensating pneumatic cushion that returns the free motor piston to its motor-compression position, and means for varying the initial pressure in said compensating pneumatic cushion in dependence on the pressure of the compressed fluid delivered by said compressor.

13. A free piston motor compressor unit of the type described comprising, in combination, a motor cylinder, at least one compression cylinder, a piston adapted to slide freely in said motor cylinder, a second piston connected to said first piston and adapted to slide in said compression cylinder, said second piston carrying out at least its main compression work on its inwardly directed stroke, means comprising at least supplementary cylinder and piston elements one rigidly connected to the first mentioned cylinders and the other carried by the free piston, the supplementary piston fitting slidably in the supplementary cylinder so as to form therewith a compensating pneumatic cushion that returns the free motor piston to its motor-compression position, a pump for delivering fuel to said motor cylinder, a control element for said pump, means for varying the initial pressure in said compensating pneumatic cushion, and means responsive to variations in said initial pressure on said pump-control element for increasing the quantity of delivered fuel with the increase of said initial pressure.

14. A free piston motor compressor unit of the type described comprising, in combination, a motor cylinder, at least one compression cylinder, a piston adapted to slide freely in said motor cylinder, a second piston connected to said first piston and adapted to slide in said compression cylinder, said second piston carrying out at least its main compression work on its inwardly directed stroke, means comprising at least supplementary cylinder and piston elements one rigidly connected to the first mentioned cylinders and the other carried by the free piston, the supplementary piston fitting slidably in the supplementary cylinder so as to form therewith a compensating pneumatic cushion that returns the free motor piston to its motor-compression position, a pump for delivering fuel to said motor cylinder, a control element for said pump, means for actuating said control element, abutment means for limiting the displacements of said control element, means for varying the initial pressure in said compensating pneumatic cushion, and means responsive to variations in said initial pressure and acting on said abutment means to move the same.

15. A free piston motor compressor unit of the type described comprising, in combination, a motor cylinder, at least one compression cylinder, a piston adapted to slide freely in said motor cylinder, a second piston connected to said first piston and adapted to slide in said compression cylinder, said second piston carrying out at least its main compression work on its inwardly directed stroke, means comprising at least supplementary cylinder and piston elements one rigidly connected to the first mentioned cylinders and the other carried by the free piston, the supplementary piston fitting slidably in said supplementary cylinder so as to form therewith a compensating pneumatic cushion that returns the free motor piston to its motor-compression position, a chamber containing a gas under pressure, means for connecting said chamber with said supplementary cylinder at the end of the return-stroke of the supplementary piston sliding therein, and a pressure reducing valve responsive to the pressure of the compressed fluid, for varying the pressure of gas admitted into said supplementary cylinder in accordance with the effective value of said fluid pressure.

16. A free piston motor compressor unit of the type described comprising, in combination, a motor cylinder, at least one compression cylinder, a piston adapted to slide freely in said motor cylinder, a second piston connected to said first piston and adapted to slide in said compression cylinder, said second piston carrying out at least its main compression work on its inwardly directed stroke, means comprising at least supplementary cylinder and piston elements one rigidly connected to the first mentioned cylinders and the other carried by the free piston, the supplementary piston fitting slidably in the supplementary cylinder so as to form therewith a compensating pneumatic cushion that returns the free motor piston to its motor-compression position, a chamber containing a gas under pressure, means for connecting said chamber with said

supplementary cylinder at the end of the return-stroke of the supplementary piston sliding therein, and a hand-operated pressure reducing valve, for varying the pressure of gas admitted in said supplementary cylinder.

17. A free piston motor compressor unit of the type described comprising, in combination, a motor cylinder, at least one compression cylinder, a piston adapted to slide freely in said motor cylinder, a second piston connected to said first piston and adapted to slide in said compression cylinder, said second piston carrying out at least its main compression work on its inwardly directed stroke, means comprising at least supplementary cylinder and piston elements one rigidly connected to the first mentioned cylinders and the other carried by the free piston, the supplementary piston fitting slidably in said supplementary cylinder so as to form therewith a compensating pneumatic cushion that returns the free motor piston to its motor-compression position, a chamber containing a gas under pressure, means for connecting said chamber with said supplementary cylinder at the end of the return-stroke of the supplementary piston sliding therein, a pressure reducing valve for varying the pressure of gas admitted into said supplementary cylinder, a pump for delivering fuel to said motor cylinder, a control element for said pump, and means responsive to variations of said pressure and acting on said pump-control element to move the same.

RAUL PATERAS PESCARA.