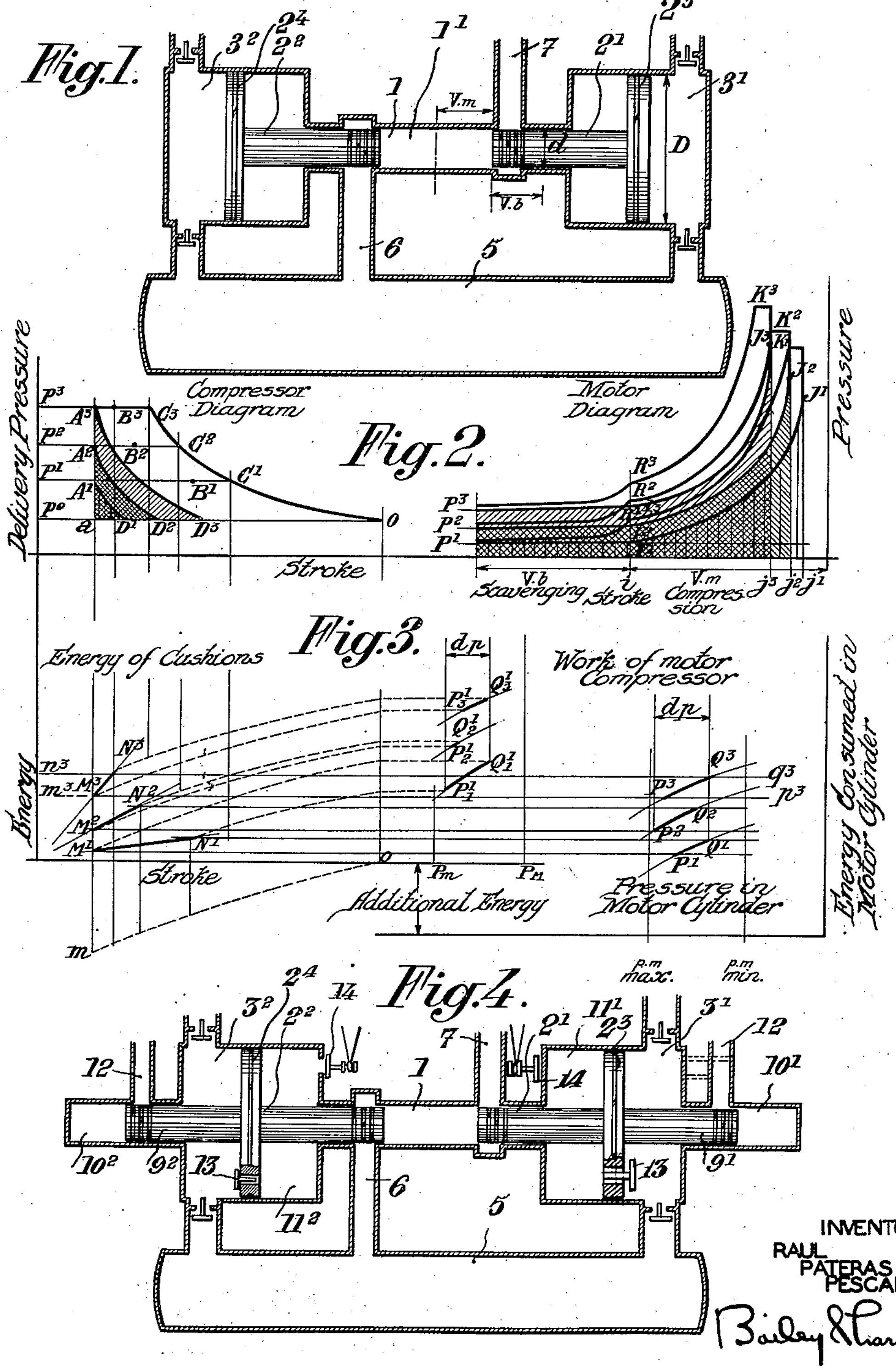
FREE PISTON DRIVING GAS GENERATOR

Filed June 1, 1936



INVENTOR
RAUL PATERAS PESCARA
Bailey & Larson
ATTORNEYS

Patented Dec. 7, 1937 2,101,412

UNITED STATES PATENT OFFICE

2,101,412

FREE PISTON DRIVING GAS GENERATOR

Raul Pateras Pescara, Paris, France

Application June 1, 1936, Serial No. 82,995
In France June 3, 1935

14 Claims. (Cl. 230—56)

This invention relates to prime movers of the free piston internal combustion type and more particularly to engines of this type directly connected with at least one gas compressor unit to form combined free piston motor compressor units; and it relates still more particularly to that type of free piston motor compressor unit hereinafter called free piston power conveying gas generators, or free piston gas generators, which is adapted to deliver a compressed energy conveying gaseous medium at relatively low temperature, said gaseous medium being subsequently available for divers uses, as, for example, to generate power in heat engines, such as gas turbines or other expansion engines.

It is known that free piston gas generators are adapted to operate under conditions of variable power output and variable gas delivery pressure, which is one of the most valuable characteristics of this type of prime mover.

The main purpose of my invention is to simplify the construction of free piston power conveying gas generators, without impairing their stability of operation under conditions of variable power output and delivery pressure.

The principal object of my invention is to provide a free piston power conveying gas generator of the type described adapted to operate under variable power outputs and variable delivery pressures, and comprising energy storage means of sufficient aggregate capacity to effect, on the return stroke, first the scavenging of the motor cylinder, and subsequently the compression of the fresh charge to a satisfactory maximum compression pressure, said satisfactory pressure being included, for all practical values of the power output and of the admission pressure, between a lower limit sufficient to insure the ignition of the injected fuel, and below which said ignition would be uncertain, and an upper limit being the maximum safe compression pressure above which the operation of the unit would become dangerous.

Another object is to provide a free piston power conveying gas generator of the type described, in which the ratios of diameter of the motor cylinder to that of the compressor cylinders, of the scavenging stroke to the compression stroke and of the compressor clearance volumes to the total piston displacement at full load, are so chosen as to make available for the return stroke an amount of energy sufficient to effect first the scavenging of the motor cylinder, and subsequently the compression of the working charge to a maximum compression pressure included between the above mentioned lower and upper limits, for all practical values of the power output and the delivery pressure.

A still further object is to provide a free piston gas generator of the type described comprising, in addition to the energy storage means constituted by the clearance spaces in the compressor cylinders, auxiliary energy storage means independent of the admission pressure, which auxiliary energy storage means may be dimensioned to keep the maximum compression pressure in the motor cylinder within any desired satisfactory limits, for all practical values of the power output and the delivery pressure.

A still further object is to provide a free piston gas generator of the type described, in which said auxiliary energy storage means are so dimensioned that, for a given value of the admission pressure, which is preferably chosen as the pressure best adapted to existing operating conditions, the maximum compression pressure in the motor cylinder remains substantially constant for all values of the power output at said admission pressure; while said maximum compression pressure remains within satisfactory limits for all other practical values of the admission pressure and power output.

A still further object is to provide a free piston gas generator of the type described, in which said auxiliary energy is supplied by feeding the compressor unit or units on the suction stroke with air at a suitable pressure other than that of the outside atmosphere, for example by supercharging said compressors, or even under certain special conditions, by undercharging the same.

Other objects and advantages of my invention will appear to a person skilled in the art, from the following description, with reference to the accompanying drawing, it being understood, of course, that said description and drawing are given by way of illustration only, and are not to be construed as limiting the scope of the invention.

In this drawing:

Fig. 1 shows diagrammatically, in longitudinal cross-section, a free piston power conveying gas generator embodying my invention.

Figs. 2 and 3 show theoretical pressure stroke and energy stroke diagrams for the compressor and motor cylinders, for the purpose of illustrating my invention.

Fig. 4 shows diagrammatically, in longitudinal cross-section, an arrangement embodying auxiliary energy storage means functioning under constant initial pressure.

In accordance with one embodiment of my invention, my free piston power conveying gas generator comprises a motor cylinder 1, two motive pistons 2^1 and 2^2 free to reciprocate in opposite directions within said cylinder, and forming between them a combustion chamber 1^1, two compressor cylinders 3^1 and 3^2 on opposite ends of said motor cylinder, and preferably in axial alignment with the same, two compressor pistons 2^3 and 2^4, which in the case illustrated, are integral with said motive pistons 2^1 and 2^2, but which may be separated from said motive pistons and connected with the same by any suitable operative connection. Said compressor cylinders 3^1 and 3^2 deliver compressed air into a common receiver 5 which is connected by a conduit 6 with the admission ports of said motor cylinder 1.

The compressed air from the receiver 5 serves first to scavenge the burned gases in the motor cylinder, and mixes with said burned gases, passing therewith into the exhaust duct 7, whence the mixture is led to the gas turbine or other energy-utilizing means. The balance of the air fed to the motor cylinder and imprisoned therein when the motive pistons 2^1 and 2^2, on the return stroke, respectively close the exhaust and admission ports, serves as combustion air for the next working stroke, and is compressed between said motive pistons.

In the known manner, the energy necessary to return the free pistons for the next working cycle is supplied mainly by the expansion of the compressed air remaining at the end of the working stroke in the clearance spaces in the compressor cylinders 3^1 and 3^2.

The free piston gas generator functions correctly if the maximum compression pressure in the motor cylinder 1 at the end of the compression stroke is included between two limits, a lower compression limit p_m below which the ignition of the injected fuel could not be relied upon, and an upper compression limit P_M above which the operating pressures in the motor cylinder might be dangerous.

In accordance with one form of my invention, in order that the maximum compression pressure be always included between the above limits p_m and P_M for all values of the stroke of the motive pistons with variable admission pressures encountered in practice, I ascribe certain suitable values to the three following independent variables: the ratio

$$\frac{d}{D}$$

between the diameters of the motor and compressor cylinders; the ratio of the clearance volumes in the compressor cylinders 3^1 and 3^2 to the full-load working stroke; and the ratio

$$\frac{Vb}{Vm}$$

between the piston displacement Vb during the scavenging period, and the piston displacement Vm during the period of compression in the motor cylinder.

Under these conditions, it is possible, as will be explained herebelow with reference to the diagrams in Figs. 2 and 3, to build a free piston unit adapted to operate satisfactorily for different admission pressures and under variable power outputs of the unit.

On the left side of Fig. 2, I have indicated the pressure stroke diagrams of the compressor cylinders 3^1 and 3^2, for three different delivery pressures P_1, P_2 and P_3; and on the right side of said figure, the pressure stroke diagrams of the motor cylinder 1 for three different admission pressures which are substantially equal, although plotted to a different scale, to the three delivery pressures P_1, P_2 and P_3 of the compressor diagrams.

On the compressor diagrams, the respective compression phases are represented by the curves OC_1, OC_2 and OC_3, all of which originate at the pressure of the outside atmosphere P_o. The respective delivery phases at the different pressures P_1, P_2 and P_3 are represented by the horizontal lines C_1A_1, C_2A_2 and C_3A_3, the expansion phases of the air retained in the clearance spaces by the curves A_1D_1, A_2D_2 and A_3D_3, and the suction phases at the atmospheric pressure P_o by the horizontal lines D_1O, D_2O and D_3O.

On the corresponding pressure stroke diagrams of the motor cylinder, the respective compression phases are indicated by the curves $I_1 J_1$, $I_2 J_2$ and $I_3 J_3$, and the expansion phases respectively by the curves $K_1 R_1$, $K_2 R_2$ and $K_3 R_3$.

The amounts of energy available for the return stroke under the different admission pressures P_1, P_2 and P_3 are respectively represented on the compressor diagrams by the cross hatched areas aA_1D_1, aA_2D_2 and aA_3D_3; and the corresponding amounts of energy consumed in the compression phases of the engine cycles are respectively represented by the cross-hatched areas ij_1J_1, ij_2J_2 and ij_3J_3.

On the left of Fig. 3, I have shown by lines M_1N_1, M_2N_2 and M_3N_3, the variations of the available return energy with different lengths of delivery stroke of the compressors, for the three different delivery pressures P_1, P_2 and P_3. It is known that the energy available from the clearance volumes is a negative linear function of the working stroke, inasmuch as, for a given delivery pressure, the return energy is proportional to the quantity of gas remaining in the clearance spaces. The straight lines M_1N_1, M_2N_2 and M_3N_3 are limited at points N_1, N_2 and N_3 which correspond to the minimum quantities of compressed gas delivered, B_1C_1, B_2C_2 and B_3C_3, said quantities being always required to scavenge the motor cylinder at the different admission pressures P_1, P_2 and P_3.

In the same Fig. 3, on the right side, I have shown, plotted against the corresponding maximum compression pressures in the motor cylinder, the amounts of energy consumed in said cylinder to compress the charge under the different admission pressures P_1, P_2 and P_3, the different curves indicating said variations being respectively P_1Q_1, P_2Q_2 and P_3Q_3.

These curves show that, for each value of the admission pressure, a possible variation in the length of the delivery stroke—which corresponds with a variation in the power output of the unit—which variation causes a variation *mn* in the available energy for the return stroke and, as a consequence, an equal variation *po* in the energy consumed for compression in the motor cylinder, reacts on the operation of the motor by producing a definite variation in the maximum pressure at the end of the compression stroke.

If the above mentioned ratios have been correctly chosen, the variations in the maximum compression pressure in the motor cylinder may be restricted, for all values of the admission pressure and of the power output encountered in practice, to a given allowable range between two limiting values p_m and p_M as mentioned above, within which range the free piston unit will function reliably and remain stable.

By way of example, it may be easily verified that, with the following values

$$\frac{d}{D}=0.3 \text{ and } \frac{Vb}{Vm}=0.5$$

the maximum compression pressure in the motor cylinder is included between the limits of 20 and 70 atmospheres, which range insures stable and reliable operation of the unit for admission pressures included between 1 and 5 atmospheres.

However, in many cases, the total amount of energy stored in the clearance spaces of the compressor cylinders is insufficient to supply alone the work entailed in compressing the charge in the motor cylinder. But, inasmuch as the variations in this energy supply only produce allowable variations in the compression pressure in the motor cylinder, the deficiency in the total energy available may be corrected by adding to said clearance space energy an additional or auxiliary supply of energy which may be constant, or approximately so, for all values of the admission pressure. With this addition, the operation of the free piston unit will be satisfactory.

The additional energy required may be supplied, according to my invention, by any suitable means, as, for example, by mechanical means, such as a spring, for storing energy during the working stroke which it will return during the return stroke; or preferably, by means of auxiliary pneumatic cushioning means; or, again, in accordance with my invention, said auxiliary energy supply may be obtained by supercharging the compressor cylinders during their suction stroke, meaning thereby by feeding said compressor cylinders with pre-compressed air, said preliminary compression pressure being chosen so that the energy supplied to said compressor pistons under constant pressure during the suction stroke be equal to the difference between the energy required to compress the charge in the motor cylinder and that available through the expansion of the air imprisoned in the clearance spaces of the compressor cylinders. By way of example with the design ratios mentioned above, the value of this precompression should be about 0.3 atmosphere.

In another embodiment of my invention, I provide the free piston gas generator with pneumatic cushioning means, after the known practice, which store a given amount of energy during the working stroke and return it to the free pistons during the return stroke. These pneumatic energy storage means may be designed to store the energy in the form of pressure or of partial vacuum. For example, as shown in Fig. 4, said pneumatic energy storage means may consist in pneumatic cushioning cylinders 10_1 and 10_2, Fig. 4, co-acting with pistons 9_1 and 9_2, said pistons 9_1 and 9_2 being either integral with the motor and compressor pistons 2_1 and 3_1, 2_2 and 3_2, as shown in Fig. 4, or connected with the same by any other suitable operative connection. Or if it is desired to store the energy in the form of a partial vacuum for use on the return stroke, the spaces 11_1 and 11_2 on the rear faces of the compressor pistons 2_3 and 2_4 may be made gas-tight, so that the motion of said compressor pistons 2_3 and 2_4 during the working stroke produces a partial vacuum in said spaces 11_1 and 11_2, as already proposed in French Patent No. 627,387.

In accordance with another form of my invention, I find it advantageous to provide the free piston gas generator with compressor cylinder clearance spaces 3_1 and 3_2, and suction cushions 11_1 and 11_2 of such dimensions that the clearance and suction cushions, co-acting, will dispose of sufficient additional energy to return the pistons and compress the charge to the desired pressure, under variable admission pressures. However, it is also possible to combine suction storage means, such as 11_1 and 11_2, with pressure storage means, such as 10_1 and 10_2; or again, to combine one or the other, or both of said storage means with the above described means consisting in supercharging or undercharging the compression cylinders (undercharging, or supplying air to said compressors at pressures below standard atmospheric pressure, applying, for example, to the case where the gas generator is designed to operate in a rarified atmosphere, or to similar conditions).

Whatever type of auxiliary energy storage means or of additional energy supply is adopted, whether of one of those described or of any other suitable type, or types, in accordance with my invention said auxiliary energy storage means or source deliver to the free pistons, on the return stroke, a given quantity of energy which is independent of the admission pressure. To this end, they may, at each stroke, be placed in communication with a supply of gaseous fluid maintained at constant pressure, as, for example, by ducts 12 in Fig. 4, which are supposed to connect with a source of air at constant pressure, such as the atmosphere or a reservoir of air at a suitable pressure other than atmospheric.

According to another variant of my invention I use the spaces 11_1 and 11_2 in the compressor cylinders as "superchargers" for the compressor cylinders themselves. To this end, I provide, as shown, by way of example, in Fig. 4, a valve 13 in each of the compressor pistons 2_3 and 2_4, and a suction valve 14 in the rear of each of the compressor cylinders 11_1 and 11_2. During the working stroke of the unit, air is drawn into spaces 11_1 and 11_2, and, on the return stroke, said air is compressed until it reaches a pressure sufficient to open the valve 13. It then flows into the compressor spaces 3_1 and 3_2, and is compressed during the next working stroke. The suction valve 14 may conveniently be either of the automatic or controlled type.

The additional energy supplied by supercharging the compressors, or that stored by the energy storage means, and returned during the return stroke, is usually variable depending on the length of the stroke, said variation being a function of certain constants, such as the initial pressure in the pneumatic cushions and/or the clearance volume of said cushions at the beginning of the return stroke.

In accordance with my invention, the energy storage means may be designed so as to maintain the maximum compression pressure within narrow limits for different values of the power output and the admission pressure; or they may also be designed in such a manner that the variations in the maximum compression pressure be reduced to a minimum for a certain admission pressure, said pressure being preferably that most commonly used in practical service.

On the diagram indicated in Fig. 3, I have shown by curve *om* the variations of the energy available from the auxiliary energy storage means, such as 10_1 and 10_2. It may be seen that the range of variation *dp* of the maximum compression pressure in the motor cylinder for different admission pressures may be particularly small or substantially nil for a certain admission pressure, which may be chosen as that commonly met in practical service.

In this embodiment, the pneumatic cushions are, of course, dimensioned so as to give a maximum compression pressure corresponding to the best efficiency of the unit at the most commonly used admission pressure.

The improvements described hereabove provide means for insuring the stability of free piston power conveying gas generators of the type described under operating conditions entailing variable power outputs and variable admission pressures to the power cylinder, through the medium of energy storage means which are independent of the admission pressure.

It is, of course, evident that these same improvements also apply to free piston gas generators designed to operate at constant admission pressures, even if these generators should be temporarily subjected to varying admission pressures, as, for example, during the starting period.

It should be understood, that I do not wish to be limited to the structural details described and illustrated, for obvious modifications thereto will occur to persons skilled in the art.

What I claim is:

1. In a driving gas generator having motor and compression cylinders and operatively connected motor and compression pistons freely movable in said cylinders, and having means for supplying at least a portion of the gas compressed in said compression cylinder to said motor cylinder to generate therein a driving gas, said generator having a variable power output and delivery pressure, and having means to return said motor piston to compression position, said means including a dead space cushion in said compression cylinder, the energy retained in which acts on the compression piston, and further including means to supply additional energy the amount of which is substantially independent of the delivery pressure and the pressures in the cylinders, the proportion between the scavenging and compressing portions of the motor piston stroke and the ratio of the diameters of the motor and compression cylinders being such that the compression pressure in the motor cylinder lies between a minimum pressure necessary to cause combustion of fuel and a maximum pressure not greater than the mechanical strength of the cylinder.

2. A device as claimed in claim 1 in which the compression pressure lies between 20 and 70 atmospheres when the admission pressure in the motor cylinder lies within the range of 1 to 5 atmospheres.

3. A device as claimed in claim 1 in which the ratio of the diameter of the motor cylinder to that of the compression cylinder lies between 0.25 and 0.5, and the ratio of the scavenging portion of the piston stroke to the compression portion lies between 1.5 and 0.25.

4. In a device as claimed in claim 1, said additional energy supply means comprising auxiliary energy storage means of a capacity substantially independent of the admission pressure, and adapted to return energy to the motor pistons during their return stroke.

5. In a device as claimed in claim 1, said additional energy supply means comprising auxiliary pneumatic energy storage means of an aggregate capacity substantially independent of the admission pressure to the motor cylinder.

6. In a device as claimed in claim 1, said additional energy supply means comprising auxiliary pneumatic energy storage means of an aggregate capacity substantially independent of the admission pressure to the motor cylinder, the mean effective pressure in said pneumatic energy storage means being different from that of the outside atmosphere.

7. In a device as claimed in claim 1, said additional energy supply means comprising auxiliary pneumatic energy storage means of an aggregate capacity substantially independent of the admission pressure to the motor cylinder, the mean effective pressure in said pneumatic energy storage means being above that of the outside atmosphere.

8. In a device as claimed in claim 1, said additional energy supply means comprising auxiliary pneumatic energy storage means of an aggregate capacity substantially independent of the admission pressure to the motor cylinder, the mean effective pressure in said pneumatic energy storage means being below that of the outside atmosphere.

9. In a device as claimed in claim 1, said additional energy supply means comprising auxiliary pneumatic energy storage means of an aggregate capacity substantially independent of the admission pressure to the motor cylinder, the mean effective pressure in said pneumatic energy storage means being different from that of the outside atmosphere, said auxiliary pneumatic energy storage means having an aggregate capacity adapted to maintain the maximum compression pressure in the motor cylinder substantially constant within the normal range of power output for a given constant value of the admission pressure.

10. In a device as claimed in claim 1, said additional energy supply means comprising means for feeding gas to the compression cylinders during their suction stroke at average pressures substantially different from that of the outside atmosphere.

11. In a device as claimed in claim 1, said additional energy supply means comprising means for feeding gas to the compression cylinders during their suction stroke at average pressures substantially above that of the outside atmosphere.

12. In a device as claimed in claim 1, said additional energy supply means comprising means for feeding gas to the compression cylinders during their suction stroke at average pressures substantially below that of the outside atmosphere.

13. In a device as claimed in claim 1, said additional energy supply means comprising suction valve means for drawing gas into the compression cylinders on the rear side of the compression pistons during the working stroke of said compression pistons, means for closing said suction valve means at the end of said working stroke, discharge valve means for discharging said gas during the return stroke of said compression pistons into said compression cylinders on the forward side of said compression pistons, thus supplying additional energy in said compression cylinders for use during the following return stroke.

14. In a device as claimed in claim 1, said additional energy supply means comprising auxiliary energy storage means of a capacity substantially independent of the admission pressure, and adapted to return energy to the motor pistons during their return stroke, said last means comprising means for feeding gas to the compression cylinders during their suction stroke at average pressures substantially different from that of the outside atmosphere.

RAUL PATERAS PESCARA.