PATENT SPECIFICATION

1,116,162

DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Improvements in or relating to Free Piston Engines.

I, HENRY BENAROYA, a French citizen, of 41 Boulevard due Commandant Charcot, Neuilly-Sur-Seine, France, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to free piston engines which may be operated as compressors delivering compressed air or as autogenerators delivering a hot mixture of gases under pressure constituted by compressed air and uncompletely expanded combustion gases. The invention refers in particular to the so called tandem free piston engines that is to say engines the driving parts of which comprise two motor cylinders and motor pistons operating therein according to a two-stroke cycle, said pistons reciprocating in phase opposition in the respective motor cylinders. In other words the pistons in one of said cylinders perform their compression strokes while the pistons in the other cylinders perform their working strokes.

The object of the invention is to improve such engines and in particular to improve the stability of their operation.

Another object of the invention is to improve the volumetric yield of the compressor cylinders of said engines.

According to the invention there is provided a tandem free piston engine comprising a first motor cylinder, first opposite motor pistons reciprocating therein, a second motor cylinder and second opposite motor pistons reciprocating therein, said first and second motor pistons being respectively interconnected in a manner such that said first motor pistons and second motor pistons reciprocate respectively in said first and second motor cylinders in phase opposition with respect to one another, at least one double acting compressor cylinder, a double acting compressor piston rigid with one of said first motor pistons, reciprocating in said double acting compressor cylinder, a casing surrounding said first motor cylinder, valve-controlled connection means between said casing and, respectively, both extremities of said compressor cylinder, said double acting compressor piston having a dead end centre position at each end of the double acting compressor cylinder, and stabilizing means controlling the pressure of the air in the double acting compressor cylinder on the side of the piston next to undergo compression such that for deviations of the piston from its dead end centre position said pressure is varied to stabilize said engine by producing a variation in the stroke of the double acting compressor piston to restore it to its dead end centre positions.

Other objects of the invention will appear as the description of illustrative but not limitative embodiments proceeds in connection with the accompanying drawings in which:—

Fig. 1 shows diagrammatically an axial section of a tandem free piston engine according to the invention;

Fig. 2 shows an embodiment of the engine according to the invention of a free piston engine, and

Fig. 3 shows diagrams of the working cycle of a compressor piston of a free piston engine according to an embodiment of the invention shown in Fig. 2, as compared with the diagram of a classical free piston engine.

In Fig. 1 there is shown a tandem free piston autogenerator established according to an embodiment of the invention. The autogenerator is provided with two preferably coaxial first and second motor cylinders *a* and *b*, in each of which reciprocate two opposite motor pistons respectively designated at 1*a*, 2*a* and 1*b*, 2*b*.

The motor pistons working in one of said motor cylinders are respectively connected with the pistons reciprocating in the other motor cylinder in a manner such that the pistons operating in one of said cylinders perform their outwards strokes or working strokes, while the pistons operating in the other cylinder perform their inwards strokes or compression strokes.

For instance, as shown in fig. 1, rigid connections are provided, on the one hand, between the exterior pistons 1*a* and 2*b* and, on the other hand, between the two interior pistons 2*a* and 1*b*. The two exterior pistons 1*a* and 2*b* may be connected by rods 3 and 4 whereas the two interior pistons 2*a* and 1*b* are cast in a single piece.

The two groups of the pistons 1*a*, 2*a* and 2*b*, 1*b* are provided with usual means (not represented) for the synchronisation of their strokes.

Advantageously, the supply of the motor cylinders *a* and *b* with air under pressure and the exhaust from said motor cylinders of a hot mixture under pressure of air and uncompletely expanded combustion gases are respectively controlled by the motor pistons themselves.

To that effect, said cylinders are provided with inlet ports respectively designated at 5*a* and 5*b* and with exhaust ports respectively designated at 6*a* and 6*b*. The exhaust ports 6*a* are connected with an outlet pipe 7*a* and the ports 6*b* communicate with an outlet pipe 7*b*, both of said outlet pipes supplying a common collector 8 which is connected through a pipe 9 with a turbine or any other receiver machine to supply the same with the driving gases which escape from said motor cylinders *a* and *b*.

Each of said motor cylinders *a* and *b* is provided with one or several fuel injectors 10 which are fed by a pump (not represented) which supply said motor cylinders with fuel when their respective motor pistons come close to their interior dead end centres.

The compressor part of the autogenerator comprises advantageously two double acting compressor elements one of which is located at one of the ends of said autogenerator and the other of which is located between the two motor cylinders. For instance the motor piston 1*a* is integral with a compressor piston 11*a* which reciprocates in a compressor cylinder 12*a* provided, in each of its extremities, with suction valves 13a and delivery valves 14*a*, these latter valves connecting, either directly or through a delivery duct 15*a*, the interior of said compressor cylinder with the interior of a casing 16*a* surrounding the motor cylinder *a* and constituting the air reservoir associated with said cylinder.

Each of the above mentioned rods 3 and 4 is secured by one of its extremities to the compressor piston 11*a* and by another of its extremities to a transverse head 21 rigid with the motor piston 2*b*.

The second compressor element comprises a compressor piston 11*b* provided between the motor pistons 2*a* and 1*b*, rigid therewith and forming with them a single block, said compressor piston 11*b* reciprocating in a compressor cylinder 12*b* inserted between the two motor cylinders *a* and *b*. The compressor cylinder 12*b* is provided in each of its extremities, on the one hand, with suction valves 13*b* and, on the other hand, with delivery valves 14*b*, these latter valves delivering compressed air either directly or through a duct 15*b*, into the casing 16*b* which surrounds the motor cylinder *b* and constitutes its air reservoir.

It must be noted that the rods 3 and 4 which interconnect the motor pistons 1*a* and 2*b* pass through the compressor piston 11*b*.

In order to control the flow delivered by such an engine, the pressure of the air to be compressed in each of the compressor cylinders and delivered into the related casing is varied at the starting of the compression stroke of the respective compressor pistons reciprocating in each of said compressor cylinders. Such a control may be effected by an overfeeding pump (not represented) constituted, for instance, by a cylinder provided at the exterior extremity of the motor cylinder *b* and having a piston slidable therein and rigid with the motor piston 2*b*, such piston then also replacing the transverse head 21 for the fixation of the rods 3 and 4.

According to another particularly advantageous embodiment of the invention applicable to tandem free piston engines provided with double acting compressor elements, part of the air compressed in the clearance volume defined in the compressor cylinder by the compressor piston, when the latter approaches one of its dead end centres, is transferred to the compartment of said compressor cylinder opposite to said clearance volume with respect to said compressor piston.

The compressor cylinders 12*a* and 12*b* are both provided with two series of ports, respectively, designated at 17*a*, 18*a* and 17*b*, 18*b*. These ports are respectively connected by ducts designated at 19*a*, 20*a* and 19*b*, 20*b*, with the clearance volumes defined in the compressor cylinders, by the compressor piston when the latter approach their respective dead end centres.

In addition these ports are so located in their respective compressor cylinders that, when the compressor piston working in each cylinder approaches one of its dead end centres, they be uncovered, at least partially by the respective compressor piston on the side thereof opposite to said clearance volumes. The greater the stroke of the compressor piston, the greater the length of said ports which is uncovered.

The time of opening of said ports increases simultaneously with the increase of the length on which said ports are uncovered by the corresponding compressor piston at the end of a stroke thereof. Thus one obtains, on the one hand, a decrease of the pressure in the cushion of compressed air in said clearance volumes, such decrease varying in function of the length of said stroke, and, on the other hand, an increase of the starting pressure of the air previously sucked in the compartments of said motor cylinder opposite to said clearance volumes, said air being compressed during the next stroke in the opposite directions of said compressor pistons.

These series of ports confer to the free piston engine and in particular to the tandem free piston engine a great stability since, upon an increase of the strokes of the compressor pistons, the energy accumulated in the clearance volumes of said compressor cylinders is decreased and the resistant work during the subsequent strokes is increased.

Of course, the converse occurs when said strokes decrease.

These two phenomenae, reduction of the accumulated energy and increase of the resistant energy, cooperate to impart a good stability to the engine.

In Fig. 1, the piston assemblies respectively constituted by the pistons 1*a*, 11*a* and 2*a*, 11*b* are shown in their internal dead end centres, the compressor pistons 11*a* and 11*b* having respectively uncovered the ports 18*a* and 17*b* on about half of their length.

Another advantage of the ports is an improvement of the volumetric yield of the compressor cylinders, such an improvement resulting from the reduction of the pressure existing in the clearance volume at the end of a compression stroke and from the increase of the starting pressure in the compartment opposite said clearance volume and containing air to be compressed and delivered in the casing 41.

This improvement of the volumetric yield is diagrammatically represented in fig. 3 which shows, on the one hand, the pressure diagram of one of the double acting compressor cylinders in mixed dotted lines and a diagram established in similar conditions for the same engine when provided with the ports according to the invention in full lines. The axis of abscissae records the displacements of the compressor piston in the compressor cylinder of the engine whereas the axis of ordinates records the pressure in one of the two compartments defined by said piston in said cylinder in function of the position of the former in the latter.

Concerning first the case of an engine devoid of said ports, the pressure for instance in the compartment *c* at the left hand side of the compressor piston 11*a*, is shown at A when said piston starts its outwards stroke. The pressure in the compartment *c* increases up to the point B at which the delivery, through delivery valves 14*a*, into the casing 16*a* of the air compressed in the compartment *c* is started.

The pressure in said compartment *c* continues to increase a little owing to the concomitant increase of the pressure in the casing 16*a* (since the inlet ports 5*a* and outlet ports 6*a* of said motor cylinder have been closed by the motor pistons 1*a* and 2*b*) until point C which corresponds to the left hand side dead end centre of the compressor piston 11*a*.

The latter then starts its inward stroke whereby the pressure in this compartment *c* decreases until point D where the suction valves 13*a* open and permit suction of air from outside, into the compartment *c* until piston 11*a* reaches again its right hand side dead end centre A.

Considering now the diagram of the same compressor element provided with ports such as 17*a*, 18*a* the pressure in the compartment *c* at the starting of the outward stroke of the piston 11*a* is shown in A_1, this pressure being higher than in the preceding case owing to the fact that some of the air compressed in the right hand side clearance volume *d* has been transferred into the compartment *c* through ports 18*a*. The delivery of the compressed air from the compartment *c* in the casing 16*a* thus starts earlier, in B_1 than in the foregoing case.

The pressure in compartment *c* continues to increase until the right hand side of piston 11*a* starts to uncover the ports 17*a* in C_1.

From this time on the pressure in compartment *c* decreases until E_1, time at which the piston 11*a* reaches its exterior dead end centre, owing to the transfer of air under pressure from the compartment *c* to the opposite compartment in said compressor cylinder through the manifold 19*a*.

However when the piston 11*a* starts its inwards stroke the suction of air in the compartment *c* will start for a position D_1 of the piston 11*a* nearer its exterior dead end centre than in the preceding case.

In the same fashion the pressure will start increasing in the compartment *c* before the end of the inward stroke of said piston, namely in F_1, owing to the fact that the ports 18*a* start to be uncovered by said piston and permit the transfer of part of the air contained in the compartment *d* through the manifold 20*a*.

It will be appreciated that the invention provides for an increase of the surface limited by the curves A_1, B_1, C_1, E_1, D_1, F_1, A_1, which surface corresponds to the volumetric yield of the engine.

Considering again the case of the tandem free piston engine according to further embodiments of the invention, the delivery of such an engine may be modified in an even more important manner, especially in the case where a reduced delivery is required, by suppressing the injection of fuel in one of the motor cylinders, for instance in the motor cylinder *b*.

In this case cylinder *b* acts only as a pneumatic accumulator of energy which stores energy when the motor pistons 1*a* and 2*a* reciprocating in the other cylinder perform their working stroke, the cushion of compressed air in the cylinder *b* restoring the energy accumulated to the pistons 1*b* and 2*b* and consequently to the pistons 1*a* and 2*a*, to ensure their respective return strokes to bring back the latter pistons in the position for which the injection in the motor cylinder *a* and the self-ignition of fuel is operated.

In the conditions which have been described, a very efficient cushion is obtained in the cylinder *b* since air is compressed therein by two pistons moving in opposite directions.

It is therefore even possible to build an engine of this nature without providing any injector means in said cylinder *b* which then becomes a simple pneumatic accumulator of return energy with opposite free pistons.

Such engine is shown in figure 2 in which the elements identical to those of fig. 1 have been designated by the same reference numbers.

The motor cylinder *b* of fig. 1 is replaced, in the engine according to fig. 3, by a cylinder *c* acting only as a pneumatic cushion not connected anymore with the collector 8 feeding the receiver machine or turbine through pipe 9.

The ports which permit communication of the interior of this cylinder *c* with the interior of the casing 16*b* are designated by 23. These ports form two groups controlled respectively by the pistons 1*b*, 2*b*. The axial distance between these groups of ports is greater than the axial distance between the groups of ports 5*b* and 6*b* shown in fig. 1.

The only object of the ports 23 is to adapt the original pressure in the cushion C to the pressure of operation of the autogenerator, said ports 23 being uncovered by the respective pistons 1*b* and 2*b* only when they come very close to their exterior dead end centres.

Finally in fig. 2 the casing 16*b* is connected through a duct 24 with the casing 16*a* surrounding the cylinder *a* which is the only motor cylinder of the engine shown fig. 2.

It should be noted that the combination of a cushion controlled by opposite pistons with compressor elements provided with the transverse ports as described hereabove leads to an engine having a particularly important stability.

While the invention has been described in connection with patricularly preferred embodiments it will be understood that the invention is not limited to these embodiments but is intended to encompass all alternatives, modifications and equivalents, as may be properly included within the scope of the invention as defined by the appended claims.

WHAT I CLAIM IS: —

1. A tandem free piston engine comprising a first motor cylinder, first opposite motor pistons reciprocating therein, a second motor cylinder and second opposite motor pistons reciprocating therein, said first and second motor pistons being respectively interconnected in a manner such that said first motor pistons and second motor pistons reciprocate respectively in said first and second motor cylinders in phase opposition with respect to one another, at least one double acting compressor cylinder, a double acting compressor piston rigid with one of said first motor pistons, reciprocating in said double acting compressor cylinder, a casing surrounding said first motor cylinder, valve-controlled connection means between said casing and, respectively, both extremities of said compressor cylinder, said double acting compressor piston having a dead end centre position at each end of the double acting compressor cylinder, and stabilizing means controlling the pressure of the air in the double acting compressor cylinder on the side of the piston next to undergo compression such that for deviations of the piston from its dead end centre position said pressure is varied to stabilize said engine by producing a variation in the stroke of the double acting compressor piston to restore it to its dead end centre positions.

2. A tandem free piston engine according to Claim 1, wherein said stabilizing means comprise an overfeeding pump supplying air to the compressor cylinders under a pressure varying responsive to the

length of the stroke of said compressor piston.

3. A tandem free piston engine according to Claim 2, wherein said overfeeding pump comprises a cylinder provided at the end of said compressor cylinder, and a piston rigidly connected to said compressor piston.

4. A tandem free piston engine according to Claim 1, wherein said stabilizing means comprise for each compressor cylinder at least one series of ports so located therein as to be uncovered, at least partially, by said compressor piston at the side thereof opposite to the clearance volume defined by said compressor piston in said compressor cylinder upon termination of a stroke of said compressor piston, and communication means connecting said ports to said clearance volume, whereby air is transferred from said clearance volume to the compartment defined by said compressor piston in said compressor cylinder opposite to said clearance volume when said compressor piston terminates said stroke.

5. A tandem free piston engine according to Claim 4, wherein said first motor cylinder and second motor cylinder are coaxial.

6. A tandem free piston engine according to Claim 4, wherein the double acting compressor cylinder is provided between said first and second motor cylinders and the double acting compressor piston is rigidly connected with those of the first and second motor pistons which are adjacent to each other in the first and second motor cylinders, and wherein the others of the first and second motor pistons are rigidly interconnected one with the other.

7. A tandem free piston engine according to Claim 6, including a second double acting compressor cylinder, a second double acting compressor piston reciprocating in the second double acting compressor cylinder and rigidly connected with said other second motor pistons, a second casing surrounding said second motor cylinder, valve controlled connection means between said second casing and respectively both extremities of said second compressor cylinder, said second compressor cylinder being also provided with at least one series of ports located therein and operating in a similar manner than in said first compressor cylinder.

8. A tandem free piston engine constructed and arranged to operate substantially as herein described with reference to the accompanying drawings.

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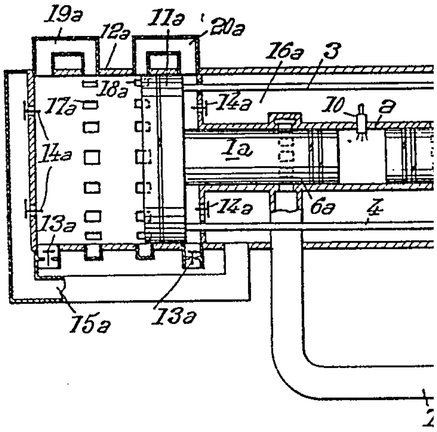
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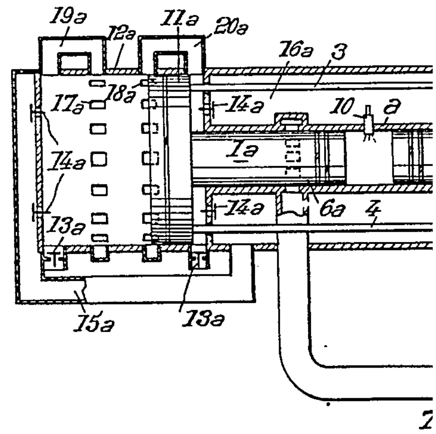
Fig.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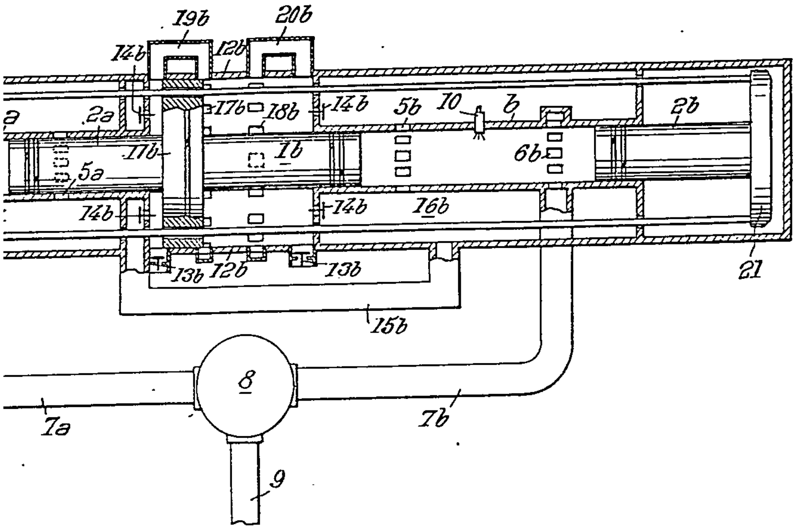
1116162 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig.1.



g.2

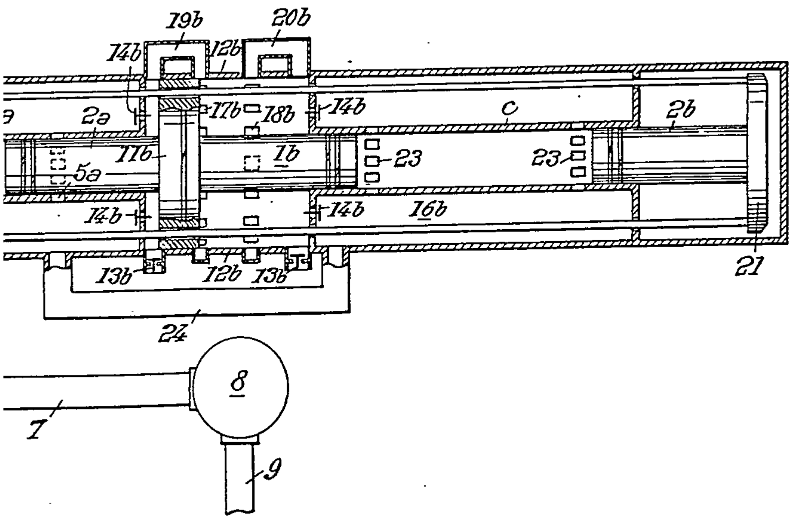


Fig.1.

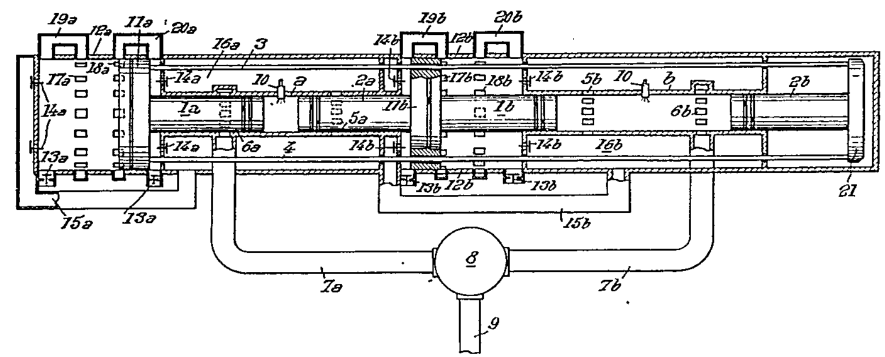

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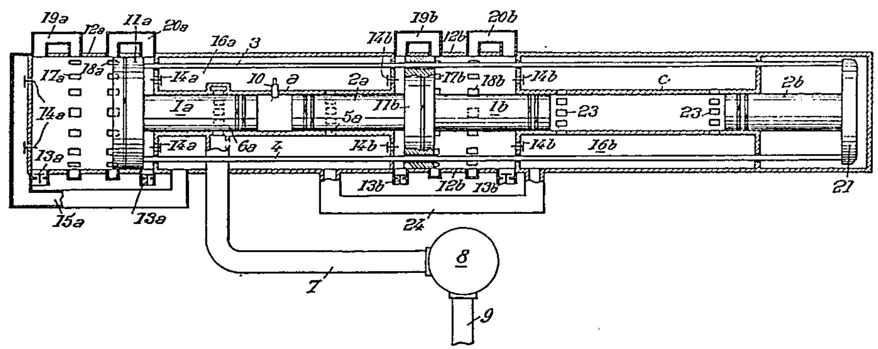
Fig.2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1116162 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

Fig. 3.