Feb. 27, 1968 R. HUBER 3,370,576

FREE PISTON MOTOR

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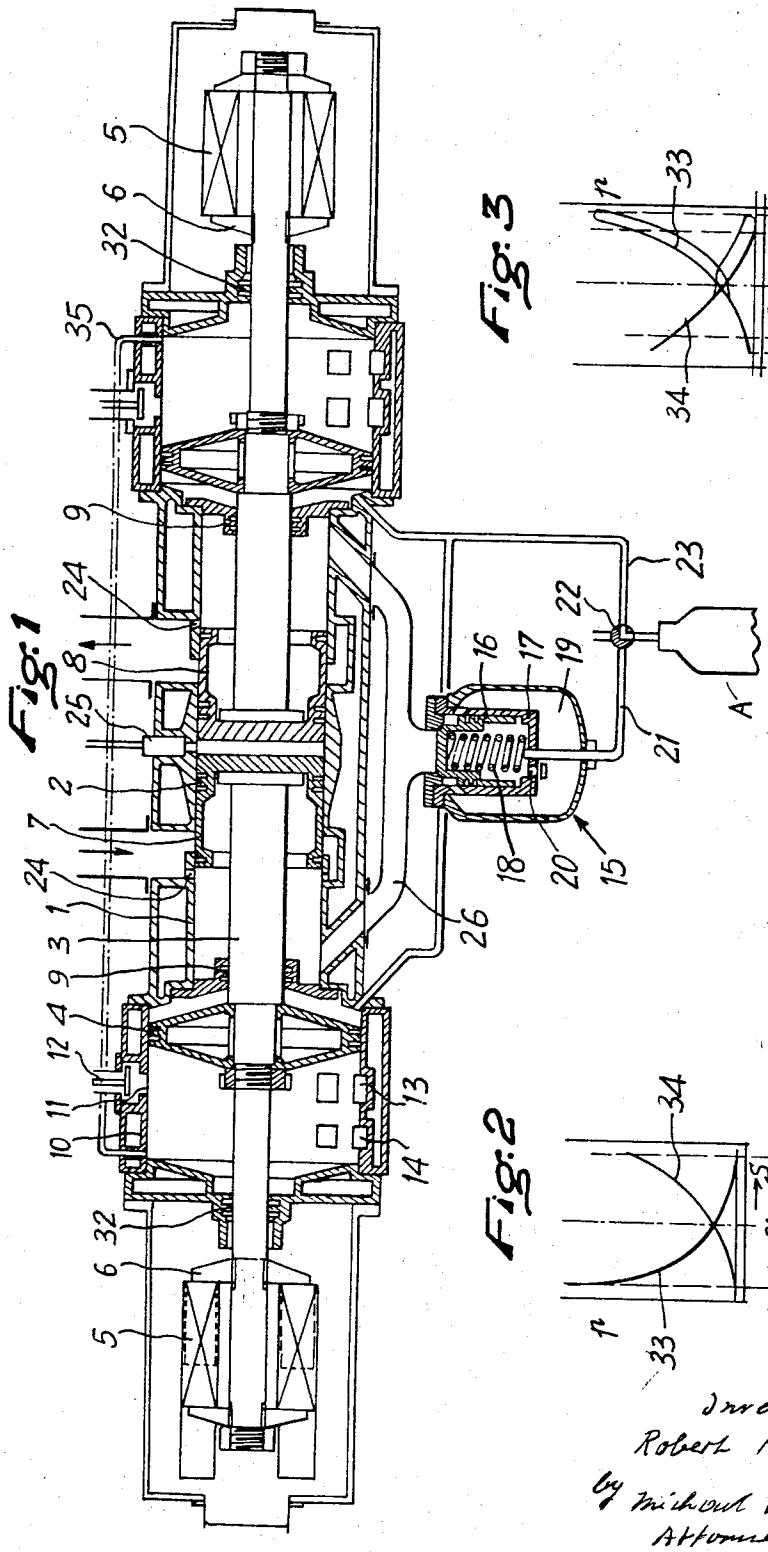

Fig. 1

Fig. 3

Fig. 2

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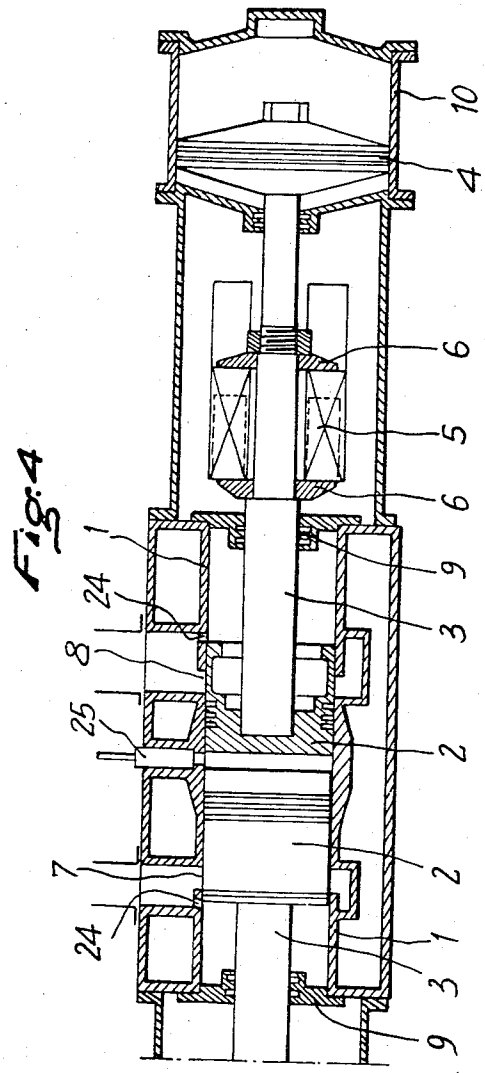
Fig. 4



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FREE PISTON MOTOR

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The present invention relates to a free piston motor which may be directly coupled to an electric generator having a rectilinear movable core, however, the free piston motor, according to the present invention, is not limited to such an application and other apparatus may be driven by the free piston motor, according to the present invention.

Free piston motors comprise a motor cylinder in which a pair of motor pistons are arranged for movement toward and away from each other, whereby combustion of fuel injected in the space between the pistons drives the latter away from each other, whereas return movement of the pistons toward each other to compress the fuel-air mixture injected therebetween is usually accomplished by pneumatic springs. Such pneumatic springs constituted by compressed air from an exterior source fed into the motor cylinder are also used at the start of the free piston motor for initially compressing the fuel-air mixture located between the opposite faces of the two motor pistons.

It is an object of the present invention to provide pneumatic springs for a free piston motor which are constructed and arranged and which cooperate with the other elements of the free piston motor in a manner to assure proper and safe operation of the latter.

It is an additional object of the present invention to provide a free piston motor in which proper synchronization of the movements of the two motor pistons of the motor will be assured.

It is a further object of the present invention to provide a free piston motor of the aforementioned kind which is constructed of relatively few and simple parts so that the motor may be constructed at reasonable cost and will operate trouble-free for extended time periods.

With these objects in view, the free piston motor, according to the present invention, mainly comprises a motor cylinder having opposite closed ends, a pair of motor pistons arranged in the motor cylinder movable along a compression stroke toward each other to an inner dead center position and an opposite suction stroke away from each other toward an outer dead center position, each of the motor pistons having a rear face and defining with the respective closed end of the motor cylinder a pressure chamber adapted to be filled with air and constituting a first pneumatic spring tending to move the respective motor piston toward the inner dead center position, a pair of additional cylinders having each at least one closed end, a pair of additional pistons respectively movably arranged in the additional cylinders and each defining with the closed end of the latter a chamber adapted to be filled with air and constituting a second pneumatic spring, connecting means connecting each of said additional pistons with the respective one of the motor pistons for simultaneous movement, injector means for injecting fuel in the space between the working pistons, starter means for feeding compressed air into said pressure chambers for moving said working pistons toward each other and moving the additional pistons with said working pistons, causing thereby combustion of the fuel in said space and subsequent movement of said pistons in the opposite direction, compressing the air in the pressure chambers of the working cylinder and the chambers of the additional cylinders, and means controlled by the pistons during subsequent strokes thereof for discharging excess air from the pressure chambers of the motor cylinder and for sucking additional air in the chambers of the additional cylinders for gradually equalizing the pressure in said chambers.

The means controlled by the pistons for gradually equalizing the pressure in the aformentioned chambers preferably comprise a pair of discharge passages in the wall of the motor cylinder arranged axially spaced from each other in such a manner to permit escape of air from the pressure chambers when the motor pistons are in their inner dead center position, and an air inlet passage for each additional cylinder providing communication between the interior thereof and the outer atmosphere, and a one-way valve in each of the air inlet passages constructed so as to permit flow of air only from the outer atmosphere in the additional cylinder, the air inlet passage communicating with the interior of the additional cylinder in the region at which the additional piston therein is located midway of its stroke.

Each of the additional cylinders may be closed at opposite ends thereof so that the additional piston therein divides the interior of each additional cylinder into an outer chamber and an inner chamber so that each additional cylinder and the additional piston therein constitutes a double acting pneumatic spring.

Preferably each of the additional cylinders is provided in the cylindrical wall thereof in the region of its outer end with at least one cavity extending in axial direction a distance greater than the axial length of the peripheral surface of the additional piston therein to permit passage of air from the outer to the inner chamber when the additional piston therein should, due to an excessive combustion of fuel in the space between the motor pistons, pass beyond its normal outer dead center position. Such cavity may also be provided in the region of the inner end of each additional cylinder, and in the region at which the additional piston therein is located midway of its stroke.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings, in which:

FIG. 1 is a schematic axial cross-section through a free piston motor according to the present invention to which a pair of rectilinearly movable core electrical generators are coupled;

FIG. 2 is a pressure diagram, the curves of which indicate the pressures in the chambers of the additional cylinders during normal operation;

FIG. 3 is a diagram similar to FIG. 2 and showing the pressures in the chambers when the additional pistons surpass their normal outer dead center position; and

FIG. 4 is a partial sectional view, similar to FIG. 1, and showing a modification of the free piston motor according to the present invention.

Referring now to the drawings, and more specifically to FIG. 1 of the same, it will be seen that the free piston motor according to the present invention mainly comprises a motor cylinder 1 having opposite closed ends, a pair of motor pistons 2 arranged in the motor cylinder movable along a compression stroke towards each other to an inner dead center position and an opposite combustion stroke toward an outer dead center position. Each of the motor pistons 2 has a rear face defining with the respective closed end of the motor cylinder 1 a pressure chamber adapted to be filled with air which, when compressed, constitutes a first pneumatic spring tending to

move the respective motor piston toward its inner dead center position. The free piston motor comprises further a pair of additional cylinders **10** closed at opposite ends and a pair of additional pistons **4** respectively reciprocably arranged therein. In the arrangement as shown in FIG. 1 the additional cylinders **10** are arranged coaxially with the motor cylinder **1** and the inner end of each additional cylinder **10** abuts against the respective outer end of the motor cylinder **1** and the cylinders are closed at the abutting ends by a single cover. Each of the additional pistons **4** is connected to the respective motor piston **2** by a piston rod **3** which extends fluid-tightly sealed through a stuffing box **9** provided in the aforementioned cover. The outer end of each additional cylinder **10** is also closed by a cover in which a stuffing box **32** is arranged coaxially with the respective piston rod **3** which extends through and beyond the stuffing box **32** to the outside of the respective additional cylinder and an electrical generator of the rectilinear type is mounted at the outer end of each piston rod for reciprocating movement therewith. The electric generator is of known construction, not forming part of the present invention, and the generator is therefore only schematically illustrated in FIG. 1. It includes a plurality of iron sheets tightly packed together by means of two clamping members **6** connected to the piston rod **3** and the sheets **5** are oscillated in a magnetic field together with the piston rods **3** to produce during such oscillation in a known manner an alternating current.

Each of the additional pistons **4** divides the additional cylinder **10** in which it is located into an inner chamber adjacent the respective outer end of the motor cylinder **1** and an outer chamber adapted to be filled with air so that each additional cylinder and the additional piston therein constitutes a second double acting pneumatic spring.

The motor cylinder **1** is provided with an inlet passage **7** for introduction of combustion air into the motor cylinder and with an outlet passage **8** for discharge of combustion gases therefrom. These passages are opened when the motor pistons **2** reach their outer dead center position. A pair of additional passages **24** are provided through the wall of the motor cylinder **1** which are axially spaced from each other in such a manner so as to be opened by the motor pistons **2** when the latter reach their inner dead center position. Injection means **25** for injecting fuel into the space between the motor pistons **2** communicate with the interior of the motor cylinder **1** midway between the opposite ends thereof.

Each of the additional cylinders **10** is provided with an air inlet passage **11** substantially midway between the ends thereof and flow of air through the inlet passage **11** is controlled by a one-way valve **12** constructed and arranged in such a manner to permit flow of air from the outer atmosphere into the cylinder **10**, while preventing flow of air into reverse direction. Each of the additional cylinders **10** is also provided with at least one, or, as shown in FIG. 1, with a plurality of cavities **13** extending from the inner surface of the peripheral wall of the cylinder **10** outwardly into the wall and having each an axial length greater than the peripheral surface of the piston **4** which engages the inner surface of the cylinder **10**. The cavities **13** are arranged in the region at which the respective piston **4** is located midway of its stroke so that the cavity **13** will permit, when the piston **4** is located between the two dead center positions thereof, passage of air from the outer chamber in the cylinder **10** to the inner chamber thereof and vice versa. Similar cavities **14** are provided in each cylinder **10** in the region of its outer extremity and these cavities **14** provide communication between the outer and the inner chamber whenever the respective piston **4** passes beyond its normal outer dead center position. The axial length of the cavities **14** is also slightly greater than the outer peripheral surface of the respective piston **4**. Similar cavities, not shown in the drawing, may be provided in the region of the inner end of each cylinder **10** to provide communication between the two chambers of each cylinder **10** when the piston **4** therein passes beyond its normal inner dead center position.

The starter **15** for starting the free piston motor comprises a cylinder **17** in which a valve member **16** is slidably arranged, normally pressed by a coil compression spring **18** against its valve seat. The interior of the cylinder **17** communicates with the interior of a reservoir **19** surrounding the cylinder **17** through a passage **20** formed in the bottom of the cylinder **17** and controlled by a one-way valve permitting flow of air from the cylinder **17** only into the reservoir while preventing flow of air in the opposite direction. The starter includes also a source of compressed air A and a cock **22** which permits in a first position flow of compressed air from the source A through a conduit **21** into the interior of the cylinder **17** and which permits in a second position, as shown in FIG. 1, flow of compressed air through the conduits **23** into the inner chambers of the cylinders **10**. Two other positions of the cock **22** permit to connect the conduit **21** or the conduit **23** to the outer atmosphere.

A conduit **35** provides communication between the outer chambers of the cylinders **10** to equalize the pressures maintained at any moment in these outer chambers and to improve synchronization of the movement of the two pairs of pistons **2** and **4** and the elements connected therewith.

In the event a plurality of free piston motors as described above are arranged in such a manner that the electric generators of rectilinear type connected thereto discharge their current in parallel into the same network, it is absolutely necessary to obtain perfect synchronization between the moving parts of the free piston motors. Such synchronization is obtained by connecting the respective inner and/or outer chambers of the free piston motors by means of conduits similar to that shown at **35** in FIG. 1.

The above-described free piston motor will operate as follows:

Fuel injected by the injector means **25** in the space between the two motor pistons **2** is combusted to drive the two motor pistons **2** and the pistons **4** connected thereto from the position shown in FIG. 1 to the outer dead center position while air in the inner chambers of the cylinders **10** expands and air in the outer chambers is compressed. A fraction of the energy produced by combustion of the fuel is transformed in electric current, while the remainder of the energy is used to compress the air in the pressure chambers of the motor cylinder **1** and in the outer chambers of the additional cylinders **10**. The energy accumulated in this manner in the two pneumatic springs is, during return movement of the pistons, in part transformed into electrical energy, but the greater part of this energy serves to compress combustion air entering through the passage **7** into the space between the motor pistons **2** when the latter are in their outer dead center position and to compress also air in the inner chambers of the cylinders **10**.

During normal operation the pressures in the inner and outer chamber of each cylinder **10** will vary during movement of the piston **4** therein along the curves **33** and **34** as shown in the diagram of FIG. 2 in which the curve **33** indicates the pressure in the outer chamber and the curve **34** the pressure in the inner chamber. The normal outer dead center position of the piston **4** is indicated **27** at which the pressure in the outer chamber has its maximum and the pressure in the inner chamber its minimum, and the normal inner dead center position of the piston **4** is indicated by the line **28** at which the pressure in the inner chamber has its maximum and the pressure in the outer chamber is minimum. The two curves **33** and **34** intersect at **31** between the outer and inner dead center positions and the passage **11** and cavity **13** in each

piston 10 are located in this region indicated by the dash-dotted line 31.

The starter 15 is operated in the following manner:

By turning the cock 22 to the position as shown in FIG. 1 compressed air from the source A will pass through the conduits 23 into the inner chambers of the cylinders 10 to move thereby the pistons 4 therein and the working pistons 2 connected thereto from the position shown in FIG. 1 to the outer dead center position thereof. Subsequently thereto the cock 22 is turned to a position in which air from the source A passes through the conduit 21 into the interior of the cylinder 17 and through the passage 20 into the reservoir 19. Subsequently thereto the cock is rapidly turned to a position in which the conduit 21 communicates with the outer atmosphere so that compressed air from the cylinder 17 is discharged and so that the valve member 16 therein is moved under the influence of the air pressure in the reservoir 19, acting through the passages at the upper end of the cylinder 17 onto a shoulder of the valve member 18 against the force of the spring 18, to the open position so that compressed air flows from the reservoir 19 through the passages 26 into the pressure chambers of the motor cylinder 1 to act on the rear faces of the motor pistons 2 and to move the latter and the pistons 4 connected thereto to the inner dead center position, compressing thereby the fuel and combustion air located between the opposite faces of the motor pistons 2 to cause combustion of this mixture, which drives the motor piston 2 and the piston 4 connected thereto to the outer dead center position thereof at which air in the pressure chambers of the motor cylinder 1 and air in the outer chambers of the cylinders 10 is compressed so that the pistons are again moved to the inner dead center position thereof and the aforementioned cycle is repeated.

During the strokes of the pistons immediately following the start, the pressure in the outer chambers of the cylinders 10 and the pressure in the pressure chambers of the motor cylinder 1 will not have yet reached their normal values. However, during each movement of the pistons from the outer to the inner dead center position thereof excess air will be discharged from the pressure chambers of the motor cylinder 1 through the passages 24 and additional air will be sucked into the outer chambers of the cylinders 10 through the air inlet passages 11. Gradually the maximum pressure in the pressure chambers of the motor cylinder 1 will decrease and the maximum pressure in the outer chambers of the cylinders 10 will increase.

It is possible that the energy provided by the combustion of the fuel injected into the space between the opposite faces of the motor pistons 2 is greater than normal, either due to a malfunction of the regulator which controls the amount of fuel injected, or through combustion of lubricating oil located in the space between the motor pistons 2, so that the motor pistons 2 and the pistons 4 connected thereto will pass beyond their normal outer dead center position. In this case the cavities 14 will permit passage of compressed air from the outer chambers in the cylinders 10 to the inner chambers thereof so that the force of the pneumatic spring constituted by the air in the outer chamber is reduced and the force by the pneumatic spring constituted by the air in the inner chamber is increased whereby the excess energy of the motor is absorbed. When the pistons 4 reach the midway position, the cavities 13 permit again an exchange of air between the outer and inner chambers of each cylinder 10 so that during a few following strokes of the pistons 4 normal pressures will again be established in the inner and outer chambers of the cylinders 10.

FIG. 3 diagrammatically indicates the pressures in the inner and outer chambers when the pistons 4 move beyond the normal outer dead center position 27 to an extreme outer dead center position 29 or beyond the normal inner dead center position 28 to an extreme position 30 and the following escape of air through the cavities 14 and 13 so that the pressure curves 33 and 34 will have the configuration as shown in FIG. 3.

FIG. 4 illustrates in a partial sectional view a modification of the above-described arrangement shown in FIG. 1 and the arrangement in FIG. 4 differs from that shown in FIG. 1 in that each of additional cylinders 10 is axially spaced from the respective outer end of the motor piston 1 and connected thereto by a spacer member as shown in FIG. 4. In this arrangement the piston rod 3 does not extend through and beyond the outer end of each additional cylinder 10 and the electrical generator 5, 6, is in this case mounted on each piston rod 3 in the space between the inner end of each additional cylinder 10 and the corresponding end of the motor cylinder 1. For reason of simplification certain parts of the free piston motor shown in FIG. 1 are eliminated from FIG. 4, but it is to be understood that the embodiment as shown in FIG. 4 includes otherwise all elements of the arrangement shown in FIG. 1 and described above.

From the above-described arrangement of the various elements of the free piston motor relative to each other it is evident that safety of operation of the motor according to the present invention is increased by the provision of the cavities 14; that the construction of the double-acting pneumatic spring constituted by the air in the two chambers of each cylinder 10 is simplified by the provision of a single suction valve 12; that synchronization between movement of the two movable units of the motor is assured by the conduit 35; and that a proper operation after start is assured by progressively transmitting potential energy from the first pneumatic spring constituted by the air in the pressure chambers of the motor cylinder to the second pneumatic spring constituted by the air in the outer chambers of the cylinders 10, which result is obtained by the cooperation of the respective pistons with the passages 24 in the motor piston 1 and the air passage 11 in the cylinders 10.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of free piston motors differing from the types described above.

While the invention has been illustrated and described as embodied in a free piston motor for driving electrical generators of the rectilinear type, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be secured by Letters Patent is:

1. A free piston motor comprising, in combination, a motor cylinder having opposite closed ends; a pair of motor pistons arranged in said motor cylinder movable along a compression stroke toward each other to an inner dead center position and an opposite combustion stroke toward an outer dead center position, each of said motor pistons having a rear face and defining with the respective closed end of said motor cylinder a pressure chamber adapted to be filled with air and constituting a first pneumatic spring tending to move the respective motor piston toward said inner dead center position; a pair of additional cylinders having at least one closed end; a pair of additional pistons respectively movably arranged in said additional cylinders and each defining with said one closed end of the latter a chamber adapted to be filled with air and constituting a second pneumatic spring; connecting means connecting

each of said additional pistons with a respective one of said motor pistons for simultaneous movement; injector means for injecting fuel into the space between said working pistons; starter means for feeding compressed air into said pressure chamber for moving said working pistons toward each other and for moving said additional pistons with said working pistons causing thereby combustion of fuel injected in said space and subsequent movement of said pistons in the opposite direction, compressing the air in said pressure chamber of said working cylinder and in said chambers of said additional cylinders; and means controlled by said pistons during subsequent strokes thereof for discharging excess air from said pressure chambers of said motor cylinder and for sucking air into said chambers of said additional cylinders to gradually equalize the pressure in said chambers.

2. A free piston motor as defined in claim 1, wherein said pair of additional cylinders are respectively arranged coaxial with said motor cylinder, and wherein said connecting means include a pair of piston rods extending fluid-tightly sealed through the respective ends of said motor cylinder and respectively connecting said motor pistons with the respective additional pistons.

3. A free piston motor as defined in claim 2, wherein said means controlled by said pistons include a pair of air discharged passages in the wall of said motor cylinder arranged axially spaced from each other in such a manner to permit escape of air from said pressure chambers when said motor pistons are in their inner dead center positions, and a pair of inlet passages for said additional cylinders providing communication between the interiors thereof and the outer atmosphere, and a one-way valve in each of said air inlet passages constructed so as to permit flow of air only from the outer atmosphere in the respective additional cylinder, each air inlet passage communicating with the interior of the respective additional cylinder in the region at which the additional piston therein is located midway of its stroke.

4. A free piston motor as defined in claim 3, wherein each of said additional cylinders is closed at opposite ends thereof so that the additional piston therein divides the interior of each additional cylinder in an inner chamber adjacent the respective end of said motor cylinder and an outer chamber and so that each additional cylinder and the additional piston therein constitutes a double-acting pneumatic spring.

5. A free piston motor as defined in claim 4, wherein each of said additional cylinders is provided in the cylindrical wall thereof and in the region of its outer end most distant from said motor cylinder with at least one cavity extending in axial direction a distance greater than the axial length of the peripheral surface of the additional piston therein to permit passage of air from the outer to the inner chamber of the additional cylinder when the additional piston therein should, due to an excessive combustion of fuel in said space, pass beyond its normal outer dead center position.

6. A free piston motor as defined in claim 5, wherein each of said additional cylinders is provided in the cylindrical wall thereof and in the region near its inner end with at least one cavity extending in axial direction a distance greater than the axial length of the peripheral surface of the additional piston therein to permit passage of air from the inner to the outer chamber of the additional cylinder when the piston therein should pass beyond its normal inner dead center position.

7. A free piston motor as defined in claim 5, wherein each of said additional cylinders is provided in the cylindrical wall thereof and in the region at which the additional piston therein is located midway at its stroke with at least one cavity extending in axial direction a distance greater than the axial length of the peripheral surface of the piston therein to permit when the piston reaches its midway position equalization of pressures in said inner and said outer chambers.

8. A free piston motor as defined in claim 7, and including conduit means providing communication between one of said chambers of one of said additional cylinders and the corresponding chamber of the other additional cylinder.

9. A free piston motor as defined in claim 7, and including conduit means providing communication between the outer chambers of the pair of additional cylinders.

10. A free piston motor as defined in claim 4, wherein said starter means include conduit means communicating with the inner chamber of each additional cylinder, a source of compressed air, and three-way valve means operable to connect said conduit means with said source of compressed air, with the outer atmosphere, and for closing said conduit means.

11. A free piston motor as defined in claim 4, wherein said additional cylinders have inner ends respectively engaging said opposite ends of said motor cylinder, and including a single cover for closing the inner end of each additional cylinder and the corresponding end of said motor cylinder, the respective piston rod extending fluid-tightly sealed through said cover and fluid-tightly sealed through and beyond the outer end of each additional cylinder, and including means driven by the free piston motor and mounted on the portion of each piston rod projecting beyond said outer end of each additional cylinder.

12. A free piston motor as defined in claim 5, wherein said additional cylinders have inner ends respectively axially spaced from said opposite ends of said motor cylinder, and including means driven by said free piston motor and mounted on the piston rods in the spaces between said inner ends of said additional cylinders and said opposite ends of said motor cylinder.

No references cited.

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