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(54) FREE PISTON ENGINE

(71) I, ANTON BRAUN, a citizen of the Republic of West Germany, of 6421, Warren Avenue, Minneapolis, Minnesota, United States of America, 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:—

This invention relates to improved free piston engines, which term includes free piston compressors.

Generally, prior free piston engines have included a pair of opposed, axially aligned pistons which may reciprocate within a cylinder, and which are designed and arranged in the cylinder so as to define a combustion chamber between the pistons and a compression chamber at each end of the cylinder. To achieve optimum operating characteristics, the free piston engines have utilized various means to synchronize the reciprocatory movement of the pistons, including a variety of arrangements of linkages and racks and pinions.

One of the primary advantages of free piston engines is that theoretically, the weight and over-all size of these engines may be reduced, as compared to the weight and size of a conventional crank type internal combustion engine of the same class or same power output operating at the same piston speeds.

However, in spite of its theoretical size and weight advantage, the successful commercial exploitation of free piston engines has been hindered by a number of problems including the fact that, for one reason or another the prior, commercially available free piston engines, and particularly free piston compressors, have not been appreciably lighter or more compact than comparable crank type internal combustion engines. One such problem is the design and arrangement of the synchronizers that have been heretofore used.

In the past, the synchronizer for free piston engines was usually positioned adjacent the cylinder and next to the central combustion chamber. Moreover, in the free piston engines utilizing the so-called "stepped" pistons, the synchronizer has been frequently positioned in the annular volume defined by the outer diameters of the larger compressor portions and the smaller combustion portions of the stepped pistons.

While locating the synchronizer in the annular volume, or adjacent the side of the engine would appear to provide the most compact and otherwise advantageous arrangement, that when the synchronizer was so positioned, it was difficult to design satisfactory intake and exhaust ducting for the central combustion chamber of the engine.

The problem of the design and arrangement of free piston engine synchronizers is further complicated by the fact that in recent years, the efficiency of free piston engines, and particularly free piston gasifiers, has been improved by increasing the compression ratio in the compressor section of the engine. As a result, the larger diameter portions of the stepped pistons have been reduced, relative to the outer diameter of the combustion portion of the stepped piston, and this correspondingly reduces the annular volume in which the synchronizer and the intake and exhaust ducting may be positioned.

In some free piston engines relatively large forces must be transmitted through the synchroniser, thereby causing the synchroniser to be of a relatively heavy construction. Moreover, these heavier synchronisers dissipate, through friction, a significant portion of the otherwise useful output energy and thereby lower the overall efficiency of the engine.

According to the present invention, an unsymmetrical free piston engine has a power

cylinder closed by a cylinder head, and a compressor cylinder, each cylinder being in a fixed location in the engine, there being in the power cylinder a power piston, and in the compressor cylinder a compressor piston, the two pistons being interconnected to move together as a unit as part of a common reciprocably movable piston assembly, a second reciprocably movable assembly, and a synchronizer which is coupled to the reciprocably movable assemblies and which controls relative movement of the two reciprocably movable assemblies synchronously in opposite directions in the engine.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a vertical cross-sectional view of an embodiment of the improved free piston engine of the present invention, taken along the central longitudinal axis of the engine, with some parts of the engine being shown broken away and others shown in elevation and with the piston assemblies being shown at one end of their strokes;

Figure 2 is a cross-sectional view of the engine taken along the section line 2—2 in Figure 1;

Figure 3 is a cross-sectional view of the engine taken along the section line 3—3 in Figure 1;

Figure 4 is a cross-sectional view of the synchronizer taken along the section line 4—4 in Figure 1;

Figure 5 is a vertical cross-sectional view of the combustion end of another embodiment of the engine of the present invention, taken along the central longitudinal axis of the engine and showing another arrangement for scavenging the combustion chamber of the engine;

Figure 6 is a vertical cross-sectional view of the combustion end of a further embodiment of the engine of the present invention, taken along the central longitudinal axis of the engine and showing still another arrangement for scavenging the combustion chamber of the engine;

Figure 7 is a cross-sectional view of the synchronizer and of a further embodiment of the engine of the present invention, taken along the central longitudinal axis of the engine, wherein a bouncer chamber is formed between the compressor section of the engine and the synchronizer;

Figure 8 is a schematic, cross-sectional view of the compressor section of a still further embodiment of the engine of the present invention, taken along the central longitudinal axis of the engine, wherein chamber means is positioned between the opposed piston assemblies in the compressor section;

Figure 9 is a schematic, cross-sectional view of the compressor section of a still further embodiment of the engine of the present invention, taken along the central longitudinal axis

of the engine, which embodiment is similar to that shown in Figure 8 except that wall means, rather than chamber means, is positioned between the opposed piston assemblies in the compressor section;

Figure 10 is a vertical cross-sectional view of another improved mechanical synchronizer which may be utilized with the engines of the present invention;

Figure 11 is a vertical cross-sectional view of a hydraulic synchronizer which may be utilized with the engines of the present invention;

Figure 12 is a cross-sectional view taken along the section line 12—12 in Figure 11; and

Figure 13 is a schematic, cross-sectional view of the compressor section and synchronizer of another embodiment of the engine of the present invention, which engine includes a plurality of engine cylinders and a synchronizer generally similar to that shown in Figure 1;

Throughout the various figures of the drawings, the same numerals will be used to designate the same parts in the various engines. Moreover, when the terms "right," "left," "right end" and "left end" are used herein it is understood that these terms have reference to the structure shown in the drawings as it would appear to a person viewing the drawings.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figures 1—4

One embodiment of the free piston engine of the present invention is shown at 21 in Figure 1. The engine 21 includes three basic functional components, that is, a combustion component, shown generally at 22, a compressor component, shown generally at 23, and a synchronizer component, shown generally at 24.

More specifically, the engine 21 comprises an end, cylindrical housing 25, a central, cylindrical housing 26 and a generally rectangular, in cross-section, synchronizer housing 27. The housings 25 and 26 have central coaxial bores 28 and 29 respectively formed therein which extend completely through the housings. In the engine shown in Figure 1, the diameter of bore 28 is smaller than the diameter of bore 29.

A cylinder head 31 closes and slightly fits within the left end 32 of bore 28. The cylinder head 31 and the end housing 25 are both fastened to the left flanged end 33 of the center housing 26 by a plurality of threaded bolts or tie-rods 34.

The left flanged end 35 of the synchronizer housing 27 is fastened to the right flanged end 36 of the central housing 26 by bolts 37. A cover plate 38 closes the open right end 39 of the synchronizer housing 27 and is fastened to the end 39 by bolts 41.

Thus, in view of the above structure it is

apparent that the engine 21 may be completely disassembled by the simple expedient of removing bolts 34, 37 and 41.

To permit cooling of the engine, generally annular cooling chambers or cavities 42 and 43 are formed in the housings 25 and 26, respectively, through which coolants may be circulated. Since conventional coolant circulating systems may be utilized with the engine 21, further details of the engine coolant system are not shown in the drawings or described herein.

A piston assembly, shown generally at 44, is positioned, for reciprocal movement, in bores 28 and 29. The piston assembly 44 includes a piston 45 which is positioned in bore 28 and a piston 46 which is positioned in bore 29. The pistons 45 and 46 may be of conventional design and construction and may include piston rings to prevent gases from leaking between the pistons and their respective bores during reciprocal movement of the pistons. A rod 47, extending from the inner face 48 of the piston 45 to the outer face 49 of the piston 46, interconnects the pistons 45 and 46 so that the pistons move together in the engine as a unit.

A second piston assembly 51 is positioned for reciprocal movement in bore 29 and includes a piston 52 which is generally similar in construction and diameter to piston 46. However, for reasons hereinafter explained, piston 52 has an axial aperture 53 formed therein. A conventional sealing ring 54 is carried in a groove formed about the periphery of the aperture 53.

The outer face 55 of the piston 45 and cylinder head 31, together with the bore 28, define an internal combustion chamber 56. In engine 21, a combustion of a fuel-air mixture in the chamber 56 results from the compression of the air or the fuel-air mixture between the outer face 55 of piston 45 and the cylinder head 31, in accordance with the principles of operation of conventional internal combustion engines. In the case of a diesel engine, a conventional fuel injector unit 57 is carried by the cylinder head 31 and communicates with the chamber 56. Of course, combustion of the fuel-air mixture in chamber 56 may also be accomplished by the use of a conventional spark plug and accompanying conventional ignition system.

Referring to Figures 1 and 2, air under pressure is introduced into the chamber 56 through one or more intake ports, one being shown at 58 and the hot combustion gases are exhausted from the chamber 56 through an exhaust port 59. The ports 58 and 59 are arranged, relative to the chamber 56, so that the chamber 56 will be "loop-scavenged" during normal operation of the engine 21. The flow through the ports 58 and 59 is controlled by the piston 45.

A generally annular scavenge air chamber 61 is formed in the housing 25 and the intake

port 58 communicates with the chamber 61 so that when the piston 45 is not blocking the port 58, air from chamber 61 flows through port 58 and into chamber 56, as more fully explained hereinafter.

A second air chamber 62 is defined by the inner face 48 of piston 45 and the outer face 49 of the piston 46 together with bore 29. Air is drawn into chamber 62 through a conventional one-way valve, shown schematically at 63, mounted in the housing 26 while the piston 46 moves to the right in bore 29. The air in chamber 62 is forced into chamber 61 by the piston 46 through conventional one-way valves, shown schematically at 64 and 65, when the piston assembly 44 moves to the left from the position shown in Figure 1. In view of the difference in the diameters of bores 28 and 29, air is introduced into chamber 61 from chamber 62 under pressure. Moreover, the volumes of chambers 61 and 62 and the dimensions of ports 58 and 59 are selected so that the pressure of the air in chamber 61 and port 58 is greater than the pressure of the gases in chamber 56 when the piston 45 is not blocking port 58.

Referring now to compressor component 23 of the engine 21, the inner faces 66 and 67 of the pistons 46 and 52, respectively, together with the bore 29, define a compressor chamber 68 between the pistons 46 and 52. As shown in Figure 3, air is drawn into the compressor chamber 68 through a conventional air filter 69 and one-way valve, shown schematically at 71, as the pistons 46 and 52 move away from each other in the bore 29. As the pistons 46 and 52 move toward each other in bore 29, air in the compressor chamber 68 is compressed to a predetermined pressure and is expelled, under pressure, from the compressor chamber through a conventional one-way valve, shown schematically at 72, and manifold 73.

The synchronizer component 24 of the engine 21 is generally positioned at the right end of the engine and as more fully explained hereinafter, is designed to transmit the instantaneous differential forces acting on the piston assemblies from one piston assembly to the other with a minimum loss of energy, due to friction, in the transmission of these forces.

More specifically, the synchronizer component 24 includes a shaft 74 which is secured at one end 75 to the inner face 66 of piston 46 and which penetrates or projects into and through the aperture 53 formed in the piston 52. The outer diameter of the shaft 74 is selected so as to prevent leakage of air between the shaft and the piston 52 while minimizing friction therebetween, during relative movement between the shaft and the piston 52. Furthermore, to avoid creation of side forces, the central longitudinal axes of the bores 28 and 29, the piston assemblies 44 and 51 and the shaft 74 are coaxial.

A synchronizer mechanism 76 is connected to the projecting end 77 of the shaft 74. The mechanism 76 includes a double-rack block 78 which is mounted on the projecting end 77 of the shaft 74 by means of a threaded pin 79 that extends through a central bore in block 78 and is threaded into the end 77 of the shaft. A shock absorbing assembly 80 is carried by the pin 79 between the block 78 and the end 77. The assembly 80 includes several sets of conventional springs 81 arranged in back-to-back, nesting contact such as, for example, "Belleville" type springs. The shock absorbing assembly 80 permits limited movement of the block 78 along the pin 79, relative to the end 77 of shaft. The purpose of this relative movement is to permit the absorption of any shocks or excessive forces imposed on the synchronizer mechanism 76, for instance, during engine start up.

Referring now to Figures 1 and 4, racks 82 and 83 are formed on the upper and lower surfaces of the block 78, respectively, so that the teeth of the racks 82 and 83 project from the block 78 in opposite directions, that is, substantially radially outwardly from the central longitudinal axis of the pin 79 and thus, of the shaft 74. The racks 82 and 83 may be of conventional design and the teeth thereof may have a conventional profile.

A pair of pinions 84 and 85 are positioned adjacent the block 78 so that the teeth of the pinions 84 and 85 engage the teeth of the racks 82 and 83, respectively. The teeth of the pinions are of meshing design and profile to the teeth of racks 82 and 83. Pinions 84 and 85 are mounted on bushings 86 for rotation about horizontally disposed shafts 87 and 88, respectively. The ends of the shaft 87 and 88 are carried by a pair of parallel, vertically arranged brackets 89 and 91 which are secured to the plate 38.

A pair of movable wall members 92 and 93 are positioned adjacent to and parallel with the brackets 89 and 91, respectively. However, there is no sliding contact between the wall members and the brackets. The wall members are connected with the outer face 94 of the piston 52 by means of integral extensions, one of which is shown at 95, of the wall members whereby the wall members 92 and 93 and the piston 52 move together as a unit.

A second pair of racks 96 and 97 are carried by and positioned between the upper and lower ends of the wall members 92 and 93, as shown in Figures 1 and 4. The teeth of the racks 96 and 97 are of meshing design and profile to the teeth of the pinions 84 and 85. The racks 96 and 97 are positioned between wall members 92 and 93 so that the teeth of the racks 96 and 97 engage the teeth of the pinions 84 and 85, respectively, whereby movement of the piston 52 and thus the racks 96 and 97 in one direction causes rotational movement of the pinions 84 and 85. This rotational

movement of the pinions, in turn, moves the double-rack block 78, and thus the shaft 74, and the piston assembly 44, in the opposite direction. In other words, the racks 82, 83, 96 and 97 and pinions 84 and 85 are arranged such that when the racks 96 and 97 are moved in one direction, the racks 82 and 83 are moved in the opposite direction and vice versa.

As noted above, the synchronizer mechanism 76 is capable of transmitting relatively large instantaneous differential forces acting on the piston assemblies 44 and 51 from one assembly to the other, with minimal losses due to friction. This minimal frictional loss in the synchronizer mechanism is due to the arrangement of the mechanism 76, and more particularly, to the arrangement of the racks 82, 83, 96 and 97 and the pinions 84 and 85 which eliminates sliding contact between the movable racks and fixed bearing surfaces and thus eliminates a major cause of frictional losses in the synchronizers as heretofore utilized with free piston engines. In other words, the arrangement of the mechanism 76 completely cancels the effect of the normal component of the forces created by the engagement between the teeth of the racks and the pinions. Furthermore, frictional losses in the mechanism 76 are further reduced since the double-rack block 78 and racks 96 and 97 are self-aligning in that they inherently seek a position relative to the pinions 84 and 85 in which the forces created by the meshing of the teeth of the pinions and the racks 82 and 84 and also the racks 96 and 97 are minimized.

OPERATION

Figures 1—4

The operation of the engine 21 may be summarized as follows: In Figure 1, the piston assemblies 44 and 51 are shown at their innermost position. Even though air is expelled from the compressor chamber 68 through the valve 72, the energy in the compressed air remaining in chamber 68 is sufficient to stop the inward movement of the pistons 46 and 52 and subsequently to force these pistons to move apart again, so that the inner faces 66 and 67 of the pistons 46 and 52 are prevented from contacting each other. As noted above, because of the synchronizer mechanism 76, the movement of piston 46 is in the mirror image of the movement of piston 52. As the pistons 46 and 52 move outwardly in bore 29 from the position shown in Figure 1, the piston 45 is also moved toward the left in bore 28. As piston 45 moves in the bore 28, it blocks ports 58 and 59 and compresses the air or fuel-air mixture in chamber 56. The compression of the air or fuel-air mixture in chamber 56 continues until the piston 45 reaches the outer end of its stroke. Combustion in chamber 56 forces the piston 45 and thus the piston 46 to move toward the right in bores 28 and 29, respectively. Again, because of mechanism 76, the piston 52 is forced to move to the left

in bore 29. The pistons 46 and 52 move inwardly toward each other until they again assume the position shown in Figure 1. Thereafter the above cycle of operation is again repeated.

As previously noted, during the leftward movement of the piston 46 air is forced from chamber 62 into the scavenge air chamber 61 through valves 64 and 65. The pressure of the air in chamber 61 is increased so that when the piston 45 again uncovers first the port 59 and then port 58, that is, after combustion in chamber 56, the air in chamber 61 scavenges the chamber 56. Moreover, when the piston 46 is moved to the right, atmospheric air is drawn into the chamber 62 through valve 63.

Also during the above cycle of operation, atmospheric air is drawn into the compressor chamber 68 through valve 71, compressed therein and expelled from the compressor chamber through the valve 72. Of course, the compressed air expelled from compressor chamber 68 may be utilized in any manner.

As noted above, one of the advantages of the improved free piston engine of this invention is that substantially vibrationless operation may be easily achieved. However, vibrationless operation is only possible if the sum of the product of the mass of the piston assembly 44, the shaft 74 and the block 78 times the distance through which these elements move plus the product of the mass of the piston assembly 51, wall members 92 and 93 and racks 96 and 97, times the distance through which these elements move is equal to zero. In other words, the mass of the elements moving in one direction in the engine times the length of their stroke must be equal to the mass of the elements moving in the opposite direction in the engine times the length of their stroke. In the most common case, the masses of the two oppositely moving elements will be equal and the lengths of their strokes will be equal, but, of course, this is not necessary.

Lastly, it should be noted that an engine, such as shown in Figures 1—4, has been constructed and has been operated, on an experimental basis. This engine has an over-all length of 35 inches as measured between the members corresponding to cylinder head 31 and plate 38 and has a maximum width of 8 inches and maximum height of 10 inches, as measured in the cross-section shown in Figure 3. The overall weight of the engine is approximately 160 pounds, not including the test instrumentation presently mounted on the engine. The output of the compressor component of the engine has been measured at approximately 80 c.f.m. with the engine running at less than 1800 cycles per minute.

ALTERNATIVE ENGINE SCAVENGING ARRANGEMENT

Figure 5

Engine 98 is identical, in structure and

mode of operation to the engine 21 except that another scavenging arrangement has been provided. This other scavenging arrangement may be utilized to improve the efficiency of the engine by reducing the amount of scavenge work which the pistons 4 and 46 must do during the time they move to the right and left, respectively.

In Engine 21, after the piston 4 blocks the port 58, the piston 46 must work against the pressure being built up in chambers 61 and 62 as the piston assembly 44 continues to move toward the left. This work tends to reduce the efficiency of the engine 21 to the degree that the pressure in chamber 61 has to be built up above the theoretical minimum pressure required for scavenging.

To improve efficiency, the housing 25 of the engine 98 includes a wall 99 which extends between and blocks communication between the bores 28 and 29. The wall 99 has a central aperture 101 formed therein through which the rod 47 projects. A sealing ring 102 prevents leakage of air between the rod 47 and the aperture 101 during relative movement between the shaft and the wall 99.

The wall 99 and the inner face 48 of the piston 45, together with the bore 28, define a chamber 103. One way valves, as shown schematically at 104 and 105, are mounted in wall 99 and permit air to flow from chamber 62 into chamber 103. One way valves, shown schematically at 106 and 107, are mounted in housing 25 and permit air to flow from chamber 103 to chamber 61. As in engine 21, atmospheric air is drawn into chamber 62 through one-way valve 63.

The operation of this scavenging arrangement is as follows: As the piston assembly 44 moves to the right, air is drawn into chamber 62 through one-way valve 63 as in engine 21. However, as piston assembly 44 and more particularly, piston 46 moves to the left, the air in chamber 62 is forced into chamber 103 through valves 104 and 105, and from chamber 103 into chamber 61 through valves 106 and 107. As long as the piston 45 has not blocked port 58, the air in chambers 103 and 61 will be forced into chamber 56 through port 58 thereby scavenging chamber 56. After the piston 45 blocks port 58, the piston 46 continues to force the air in chamber 62 into chamber 103 and also partially into chamber 61. However, as the piston assembly 44 continues to move to the left, the volume of chamber 103 increases at a rate related to the rate at which the volume of chamber 62 decreases. Thus, the pressure against which the piston 46 is required to work is not as great as in engine 21 and as a result, the piston 46 is forced to do less work during its leftward movement in engine 98.

Another advantage of engine 98 is that if oil leaks past piston 45, the wall 99 prevents

the oil from leaking into the bore 29, thereby reducing the chances of contaminating the air in compressor chamber 68.

Figure 6

5 The engine 108 is similar to the engine 21, in structure and mode of operation, except that it includes still another arrangement for scavenging the combustion chamber 56. As in engine 98, the engine 108 includes a wall 109
10 that prevents communication between the bores 28 and 29. Wall 109 is identical to wall 99 except that the former does not have any one-way valves mounted therein. Rather, the housing 25 includes one-way valves, shown
15 schematically at 111 and 112, which permit atmospheric air to be drawn directly into chamber 103. One-way valves, shown schematically at 113 and 114, permit the air in chamber 103 to flow from that chamber into
20 chamber 61. Moreover, the one-way valve 63 in housing 26 has been replaced by a check valve, shown schematically at 115, which permits leakage air to escape from chamber 62
25 but does not permit atmospheric air to be drawn into chamber 62. Moreover, check valve 115 may also be positioned in wall 109 to operate in a similar fashion.

During operation of the engine 108, movement of the piston assembly 44 to the left
30 causes any excess air to be expelled from chamber 62, through check valve 115, while at the same time piston 45 causes air to be drawn into chamber 103 through valves 111 and 112. During movement of piston assembly
35 44 to the right, the piston 45 forces the air in chamber 103 to flow into chamber 61 through valves 113 and 114 and the air in chamber 61 to scavenge the combustion chamber 56 in a still more efficiently phased
40 relationship than that in engines 21 and 98. Likewise, as the piston 46 moves to the right, a partial vacuum or negative pressure is created in chamber 62, thereby causing chamber 62 to act as a negative bouncer chamber. The
45 utilization of chamber 62 as a negative bouncer chamber, of course, retards, the inward movement of the piston assemblies while assisting their outward movement.

The engine 108 may be modified by eliminating valves 113 and 114 with unvalved piston operated ports or fluid diodes so that there
50 may be free communication between chambers 103 and 61 and port 58. In this case the chamber 61 and valve 113 and 114 are replaced by a passage directly interconnecting chambers 103 and 56. Furthermore, the engine 108 can be further modified by replacing
55 valves 111 and 112 also with piston operated ports or fluid diodes. Moreover, as noted, valve 115 may also be positioned in wall 109, if desired, and when so positioned, would operate in the same manner as described above. In addition, the chamber 62 of engine 108 may
60 also be used as a positive bouncer chamber. When this is the case, check valve 115 is ar-

ranged to permit air to be drawn into the chamber 62 to replenish the air in that chamber which generally would leak past piston 46 into chamber 68.

BOUNCER CHAMBER

Figure 7

Engine 116 may be identical to engine 21, both in structure and mode of operation, except that engine 116 has a bouncer chamber
75 formed between the piston 52 and the synchronizer mechanism 76. More specifically, a wall 117 is clamped between the end flanges 35 and 36 and extends across the right end of the bore 29 so that the bore 39 is isolated from the interior of the synchronizer housing
80 27. The wall 117 includes a central aperture 118 through which the shaft 74 projects. A conventional sealing ring 119 is carried by the wall 117 adjacent the aperture 118 so as to prevent leakage of air between the wall 117
85 and the shaft 74 during relative movement therebetween.

Instead of the extensions 95, the wall members 92 and 93 are connected with the outer face 94 of the piston 52 by a plurality
90 of relatively thin arms 120 which are spaced from the central longitudinal axis of the shaft 74. Sealed apertures, not shown, are formed in the wall 117 through which the arms 120
95 project.

The wall 117 and the outer face 94 of the piston 52, together with the bore 29, define a bouncer chamber 121. A check valve, schematically at 122, is mounted in the housing
100 26 and permits air to be expelled from chamber 121. Thus, the chamber 121 functions as a negative bouncer chamber. However, if valve 122 were changed so that it would permit air to be drawn into chamber 121, then, of course, chamber 121 would function as a
105 positive bouncer chamber.

Another advantage of engine 116 is that the wall 117 isolates the bore 29 from the synchronizer mechanism 76 thereby preventing synchronizer lubricant from leaking into the bore
110 29, thereby minimizing the chances of contaminating the air in the compressor chamber 68.

ALTERNATE COMPRESSOR CHAMBER ARRANGEMENTS

Figure 8

The engine 123, as shown schematically in Figure 8 may be generally similar to the engine 21, both in structure and in mode of operation; however, the engine 123 includes
120 an alternative compressor chamber arrangement which permits high volumetric efficiencies to be achieved by the compressor component of the engine.

The engine 123 also includes a wall 124
125 which is similar to the walls 99 and 109 of engines 98 and 108, respectively, in that the wall 124 prevents communication between the bores 28 and 29. As in engines 98 and 108, the advantage of the wall 124 is that it pre-

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vents oil from the combustion component 22 from leaking into the bore 29 and thereby reducing the chances of contaminating the fluid being compressed in compressor section 24. Furthermore, with the wall 124, the chamber 62 between the piston 46 and the wall 124 may be utilized as a bouncer chamber or, if desired, as a scavenge-pump chamber for the combustion section 22.

- 10 In engine 123, a hollow annular member 12 is positioned in the space 126 formed in bore 29 between the inner faces 66 and 127 of the pistons 46 and 128. The piston 128 may be similar in structure to piston 52, although it may have a different construction since it functions as a bouncer piston. Moreover, if desired, the piston 128 need not function as a bouncer piston or for that matter, as a piston at all, but can simply function as a counter-balancing weight and, as such, it can, of course, have various constructions.

- 20 The hollow member 125 has a central aperture 129, including a sealing ring, not shown, formed therein through which the shaft 74 may slidably project. However, the central aperture 129 does not communicate with the interior of the member 125.

- 30 The member 125 divides the bore 29 into a left portion 131 and a right portion 132 and prevents communication between these portions. Conventional one-way valves, two of which are shown schematically at 133 and 134, are mounted in the housing 26 adjacent the member 125 and permit atmospheric air, or any other fluid to be compressed, to be drawn into the portion 131 of the bore 29 when the piston 46 is moving to the left in bore 29, i.e., away from member 125. Conventional one-way valves two of which are shown schematically at 135 and 136, are mounted in the member 125 adjacent the inner face 66 of the piston 46 and permit compressed air or fluid to be forced into the interior chamber 137 of the member 125 when the piston 128 moves to the right in bore 29, i.e., toward the member 125. The interior chamber 137 of the member 125 communicates with a manifold 138 which directs the compressed air, or fluid, therein away from the engine 123. Thus, in engine 123, the air or fluid is compressed solely by the action of the piston 46, and the piston 128, together with the portion 132 of the bore 29, may either function as a bouncer chamber or the piston 128 may merely function as a movable weight for the purposes of achieving vibrationless operation of the engine. It also should be noted that if desired, the valves 133, 134, 135 and 136 could also be positioned in portion 132 so that this portion, rather than portion 131, would function as the compression chamber.

- 60 As noted above, one of the primary advantages of the engine 123 is that the use of member 125 permits the volumetric efficiency of the compressor component of the engine to

be significantly increased. This is because the engine may be designed to have an extremely small clearance volume as there is a minimal incidental overstroke of the piston 46 because the return energy i.e., the energy required to drive piston 45 to the left for the next combustion in chamber 56 may be supplied by the piston 128 functioning as a bouncer piston. By the use of member 125 and the use of piston 128 as a bouncer piston, the size of the compressor clearance volume may be independently varied without affecting the other thermodynamic characteristics of the engine.

Also, as would be expected, the smaller clearance volume and concomitant higher volumetric efficiency of the engine 123 increases valve-opening time and thus the life of the valves utilized in the compressor component of the engine 123. Furthermore, since the valves 135 and 136 are not mounted about the circumference of housing 26, the area available for mounting the valves 133 and 134 and the valves 135 and 136 is optimized. Moreover, this arrangement of the valves 133, 134, 135 and 136 results in less power required for same air-output.

Figure 9

The engine 139 is similar to the engine 21, both in structure and mode of operation, except that the engine 139 includes another alternate clearance volume arrangement. In engine 139, a wall 141 is clamped between flanged portions 142 and 143 formed in a housing 140 and this wall 141, like member 125 in engine 124, divides the bore 29 into two separate portions 131 and 132. The wall 141 has a central aperture 144 through which the shaft 74 may slidably project.

The wall 141 and the inner face 67 of the piston 52 define a compressor chamber 145. Conventional one-way valves, one of which being shown schematically at 146, are positioned in the housing 27 adjacent the flange 143 and permit atmospheric air or other fluids to be compressed to be drawn into the compressor chamber 145 while the piston 52 is moving to the right, i.e., away from the wall 141. Other conventional one-way valves, one of which being shown schematically at 147 are positioned in the housing 27 adjacent the flange 143 and permit compressed air or fluid to be discharged from the compressor chamber 145 during the time the piston 52 is moving to the left, i.e., toward the wall 141. Unlike in engine 124, compression of air or fluid, is accomplished entirely by the piston 52 and the piston 46 and the portion 131 of the bore 29 merely function as a bouncer chamber.

The compressor chamber arrangement shown in engine 139 is simpler, from a structural standpoint, than the corresponding compressor chamber arrangement in engine 124, and thus is less expensive to manufacture. Moreover, it should be noted that the portion 132 can be used as the compressor chamber

by placing the valves 146 and 147 on the left side of wall 141, and in such a case, the piston 52, of course, could function as a bouncer piston or would not have to function as a piston at all, but merely could be used to balance the engine.

ALTERNATIVE SYNCHRONIZER MECHANISMS

Figure 10

10 Engine 148 may be identical to the engine 21, both in structure and mode of operation, except that the synchronizer mechanism 76 in engine 21 has been replaced by a linkage mechanism 149. While synchronizer mechanism 76 and linkage mechanism 149 both

15 basically perform the same function with respect to the engine, that is, transmit the instantaneous differential forces acting on the piston assemblies 44 and 51 from one assembly to the other, the linkage mechanism 149 differs structurally from the mechanism 76.

20 More specifically, the linkage mechanism 149 includes three sets of links: 151 and 152; 153 and 154; and 155 and 156. A pair of plates, one of which is shown at 157, are spaced equidistant from the central longitudinal axis of the shaft 74 and are attached at one end to the outer face 94 of the piston 52. A pair of pins 158 and 159 extend between

25 the other ends of these plates at two points spaced equidistant from the central longitudinal axis of the shaft 74. These pins 158 and 159 pivotally interconnect the plates to one end of the links 155 and 156. The other ends of the links 155 and 156 are pivotally connected to one end of the links 153 and 154, respectively. The other ends of the links 153 and 154 are pivotally connected to one end of the links 151 and 152, respectively. The other ends of the links 151 and 152 are pivotally connected to the bifurcated end 161 of the shaft 74 by means of a pin 162. Arms 163 and 164 are attached, at one end, to cover plate 38 and extend to the left from plate 38 in a direction parallel to but spaced equidistant from the central longitudinal axis of the shaft 74. The links 153 and 154 are pivotally connected at points 165 and 166 to the other end of the arms 163 and 164, respectively.

30 As noted above, the linkage mechanism 149 synchronizes the movement of the piston assemblies 44 and 51. The advantage of linkage mechanism 149, compared to synchronizer mechanism 76, is that the mechanism 149 is relatively inexpensive to manufacture.

Figures 11 and 12

35 Engine 167 may be identical to the engine 21, both in structure and mode of operation, except that the engine 167 utilizes a hydraulic synchronizer 168, rather than synchronizer mechanism 76. The hydraulic synchronizer 168 performs basically the same function, with regard to the engine, as does synchronizer mechanism 76.

40 Hydraulic synchronizer 168 comprises a

generally rectangular reservoir body 169. The body 169 has a circular flange 171 formed at one end thereof which is used to attach the body 169 to the flanged end 36 of the housing 26. The body 169 has a central bore 172 and two smaller bores 173 and 174 drilled therein. The central longitudinal axis of the bore 172 is coaxial with the central longitudinal axis of the shaft 74 and the central longitudinal axes of the bores 173 and 174 are parallel to but spaced equidistant from the central longitudinal axis of the bore 172. The diameters of the bores 172, 173 and 174 may be selected so that the cross-sectional area of the bore 172 is equal to the sum of the cross-sectional areas of the bores 173 and 174.

A pair of ports 175 and 176 permit fluid communication between the bores 172 and 173 and between the bores 172 and 174, respectively.

The end 177 of the shaft 74 includes a plunger 178 which is of a diameter to fit snugly in the bore 172. A pair of shafts 179 and 181 are attached, at one end, to the outer face 94 of the piston 52 and are arranged so that their other ends 182 and 183 project within the bores 173 and 174, respectively. Plungers 184 and 185 are carried by the ends 182 and 183 and are of such a diameter as to fit snugly within the bores 173 and 174.

During the operation of the engine the bores 172, 173 and 174, to the right of the plungers 178, 184 and 185, are filled with hydraulic fluid so that movement of the plunger 178 in one direction causes a corresponding movement in the opposite direction of the plungers 184 and 185 and vice versa.

MULTI ENGINE ARRANGEMENTS

Figure 13

As noted above, the principles of this invention are applicable to engines having a plurality of engine cylinders. One example of such an application is engine 186 which includes a first engine cylinder 187 having axially opposed pistons 188 and 189 positioned therein for reciprocal movement. A second engine cylinder 191 is positioned adjacent to engine cylinder 187 so that the central longitudinal axes of the engine cylinders 187 and 191 are substantially parallel. The engine cylinder 191 also has a pair of axially opposed pistons 192 and 193 positioned therein for reciprocal movement. The pistons 188 and 192 may be identical to piston assembly 44 in engine 21 and the pistons 189 and 193 may be identical to piston assembly 51 in engine 21.

A pair of shafts 194 and 195 are fastened at one end to the inner faces 196 and 197, respectively, of the pistons 188 and 192 and slidably project through central apertures 198 and 199 formed in the pistons 189 and 193, respectively. Each of the pistons 189 and 193 has a pair of extensions, one of each pair being shown at 201 and 202, attached to its outer face 203 and 204 thereof. In structure and

in mode of operation, each of the engine cylinders 187 and 191 may be identical to the engine 21 shown in Figure 1.

A transverse bar 205 is fastened to and carried by the other ends of the shafts 194 and 195. The bar 205, in turn, carries the double-rack block 78 of the synchronizer mechanism 206 which may be identical in structure and mode of operation to the synchronizer mechanism 76, utilized in the engine 21, with the only difference being that the component parts of the mechanism 206 are of larger dimension than the corresponding parts in mechanism 76. The extensions 201 and 202 are part of wall member 93 and are fastened to and carry the racks 96 and 97 of the mechanism 206 so that the teeth of these racks engage the teeth of the pinions 84 and 85. The teeth of the pinions 84 and 85 engage the teeth of the racks 82 and 83 formed on the block 78. As noted above, the synchronizer mechanism 206 functions in the same manner as the mechanism 76 so that movement of the pistons 188 and 192 in one direction causes corresponding movement of the pistons 189 and 193 in the opposite direction.

The utilization of the principles of this invention permit, contrast to many prior engines, considerable freedom in designing free piston engines since the synchronizer and the principal sections of the engine can be designed substantially independently of each other thereby permitting, for any given engine, an optimum design for the engine sections and the synchronizer to be achieved. Because it is believed that the principles of this invention have broad applications, the term "engine" has been used herein in a generic sense so as to include all types of free piston engines, such as free piston compressors and free piston gasifiers.

Of course, it will be apparent to those skilled in the art that the features of the various engines disclosed herein may be used interchangeably and in combination. It should also be obvious that still further modifications of the engines disclosed herein are possible. For example, in larger engines, the synchronizer structure may be substantially positioned within and carried by the penetrated piston assembly, that is, the piston corresponding to piston assembly 51 in engine 21. Further, the penetrated piston assembly may have only limited movement within the engine cylinder and in fact, may not, strictly speaking, actually function as a piston.

Moreover, the rack 78 of the synchronizer mechanism 76 in the engine 21 may have more than two racks formed thereon. Of course, each additional rack must engage a separate pinion that in turn engages another rack carried by the adjacent piston assembly 51. Again, the teeth of each rack may project substantially radially outwardly from the central longitudinal axis of the rack so as to provide adequate space for positioning the pinions. The advan-

tage of utilizing more than two racks is that the synchronizer is able to transmit greater forces and/or that if desired, inexpensive, lower quality materials may be utilized in the synchronizer. Furthermore, as another example of a modification of the mechanism 76, the rack 78 and pinions 84 and 85 in mechanism 76 may be replaced by oscillating gear means which engage the racks 96 and 97 and which are connected with the shaft 74. Likewise, the racks 96 and 97 and pinions in mechanism 76 may also be replaced by oscillating gear means which engage the racks 82 and 83 and which are connected with the piston 52.

The synchronizer is the subject of Patent Specification No. 29145/70 (Serial No. 1210533), divided from this application.

WHAT I CLAIM IS:—

1. An unsymmetrical free piston engine having a power cylinder closed by a cylinder head, and a compressor cylinder, each cylinder being in a fixed location in the engine, there being in the power cylinder a power piston and in the compressor cylinder a compressor piston, the two pistons being interconnected to move together as a unit as part of a common reciprocally movable piston assembly, a second reciprocally movable assembly and a synchroniser which is coupled to the reciprocally movable assemblies and which controls relative movement of the two reciprocally movable assemblies synchronously in opposite directions in the engine.

2. An engine as claimed in Claim 1 in which the combustion and compressor cylinders are co-axial.

3. An engine as claimed in either of the preceding claims in which the compressor piston has first and second faces in the compressor cylinder.

4. An engine as claimed in any of the preceding claims in which the power piston has two faces.

5. An engine as claimed in any of the preceding claims in which the second reciprocally movable assembly also comprises a piston.

6. An engine as claimed in Claim 5 in which the piston comprising a part of the second reciprocally movable assembly is a second compressor piston.

7. An engine as claimed in any of the preceding claims in which the compressor cylinder is at one end of the housing.

8. An engine as claimed in any of the preceding claims including a second compressor piston which is penetrated by a shaft carrying the first compressor piston.

9. An engine as claimed in Claim 8 in which the first and second compressor pistons act in opposition to each other.

10. An engine as claimed in any of the preceding claims including a wall positioned adjacent the or one of the compressor pistons defining a bounce chamber between a face of that piston and the wall,

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in mode of operation, each of the engine cylinders 187 and 191 may be identical to the engine 21 shown in Figure 1.

A transverse bar 205 is fastened to and carried by the other ends of the shafts 194 and 195. The bar 205, in turn, carries the double-rack block 78 of the synchronizer mechanism 206 which may be identical in structure and mode of operation to the synchronizer mechanism 76, utilized in the engine 21, with the only difference being that the component parts of the mechanism 206 are of larger dimension than the corresponding parts in mechanism 76. The extensions 201 and 202 are part of wall member 93 and are fastened to and carry the racks 96 and 97 of the mechanism 206 so that the teeth of these racks engage the teeth of the pinions 84 and 85. The teeth of the pinions 84 and 85 engage the teeth of the racks 82 and 83 formed on the block 78. As noted above, the synchronizer mechanism 206 functions in the same manner as the mechanism 76 so that movement of the pistons 188 and 192 in one direction causes corresponding movement of the pistons 189 and 193 in the opposite direction.

The utilization of the principles of this invention permit, contrast to many prior engines, considerable freedom in designing free piston engines since the synchronizer and the principal sections of the engine can be designed substantially independently of each other thereby permitting, for any given engine, an optimum design for the engine sections and the synchronizer to be achieved. Because it is believed that the principles of this invention have broad applications, the term "engine" has been used herein in a generic sense so as to include all types of free piston engines, such as free piston compressors and free piston gasifiers.

Of course, it will be apparent to those skilled in the art that the features of the various engines disclosed herein may be used interchangeably and in combination. It should also be obvious that still further modifications of the engines disclosed herein are possible. For example, in larger engines, the synchronizer structure may be substantially positioned within and carried by the penetrated piston assembly, that is, the piston corresponding to piston assembly 51 in engine 21. Further, the penetrated piston assembly may have only limited movement within the engine cylinder and in fact, may not, strictly speaking, actually function as a piston.

Moreover, the rack 78 of the synchronizer mechanism 76 in the engine 21 may have more than two racks formed thereon. Of course, each additional rack must engage a separate pinion that in turn engages another rack carried by the adjacent piston assembly 51. Again, the teeth of each rack may project substantially radially outwardly from the central longitudinal axis of the rack so as to provide adequate space for positioning the pinions. The advan-

tage of utilizing more than two racks is that the synchronizer is able to transmit greater forces and/or that if desired, inexpensive, lower quality materials may be utilized in the synchronizer. Furthermore, as another example of a modification of the mechanism 76, the rack 78 and pinions 84 and 85 in mechanism 76 may be replaced by oscillating gear means which engage the racks 96 and 97 and which are connected with the shaft 74. Likewise, the racks 96 and 97 and pinions in mechanism 76 may also be replaced by oscillating gear means which engage the racks 82 and 83 and which are connected with the piston 52.

The synchronizer is the subject of Patent Specification No. 29145/70 (Serial No. 1210533), divided from this application.

WHAT I CLAIM IS:—

1. An unsymmetrical free piston engine having a power cylinder closed by a cylinder head, and a compressor cylinder, each cylinder being in a fixed location in the engine, there being in the power cylinder a power piston and in the compressor cylinder a compressor piston, the two pistons being interconnected to move together as a unit as part of a common reciprocally movable piston assembly, a second reciprocally movable assembly and a synchroniser which is coupled to the reciprocally movable assemblies and which controls relative movement of the two reciprocally movable assemblies synchronously in opposite directions in the engine.

2. An engine as claimed in Claim 1 in which the combustion and compressor cylinders are co-axial.

3. An engine as claimed in either of the preceding claims in which the compressor piston has first and second faces in the compressor cylinder.

4. An engine as claimed in any of the preceding claims in which the power piston has two faces.

5. An engine as claimed in any of the preceding claims in which the second reciprocally movable assembly also comprises a piston.

6. An engine as claimed in Claim 5 in which the piston comprising a part of the second reciprocally movable assembly is a second compressor piston.

7. An engine as claimed in any of the preceding claims in which the compressor cylinder is at one end of the housing.

8. An engine as claimed in any of the preceding claims including a second compressor piston which is penetrated by a shaft carrying the first compressor piston.

9. An engine as claimed in Claim 8 in which the first and second compressor pistons act in opposition to each other.

10. An engine as claimed in any of the preceding claims including a wall positioned adjacent the or one of the compressor pistons defining a bounce chamber between a face of that piston and the wall.

11. An engine as claimed in Claim 8 or Claim 9 including a wall between the first and second compressor pistons, first and second chambers being formed in the compressor cylinder between the wall and the first and second compressor pistons respectively.

12. An engine as claimed in Claim 11 in which one of the first and second chambers is a positive bouncer chamber.

13. An engine as claimed in any of the preceding claims including a wall between the power piston and the compressor piston and a scavenge chamber between one face of the power piston and the wall, a scavenge passage in the housing connecting the scavenge chamber with the power cylinder and disposed to permit free communication as the power piston approaches the wall, for scavenging using compressed air within the scavenge chamber.

14. An engine as claimed in Claim 13 in-

cluding an additional scavenge chamber between the face of the compressor piston and the wall and valve-controlled connections between the two scavenge chambers.

15. A multi-cylinder free piston engine as claimed in any of the preceding claims, all the engine cylinders being substantially identical, with parallel axes spaced from one another in directions perpendicular to these axes, the synchroniser being connected to all cylinders.

16. An engine as claimed in Claim 15 in which the synchroniser is at one end of the engine.

17. An unsymmetrical free piston engine constructed and arranged substantially as herein specifically described with reference to Figures 1 to 4, any of Figures 5 to 13 of the accompanying drawings.

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