United States Patent [19]
Foster

[11] **3,895,620**
[45] **July 22, 1975**

[54] **ENGINE AND GAS GENERATOR**

[76] Inventor: **Berry W. Foster**, 2415 Thomas Ave., Redondo Beach, Calif. 90278

[22] Filed: **Dec. 4, 1972**

[21] Appl. No.: **312,042**

Related U.S. Application Data

[62] Division of Ser. No. 70,387, Sept. 8, 1970, Pat. No. 3,712,276.

[52] **U.S. Cl.** .... **123/197 R;** 123/46 R; 123/51 R; 123/56 R

[51] **Int. Cl.** **F02b 77/00;** F02b 75/24

[58] **Field of Search** .... 123/197 C, 46 R, 46 B, 123/51 BB, 51 BA, 51 B, 51 R, 56 R

[56] **References Cited**

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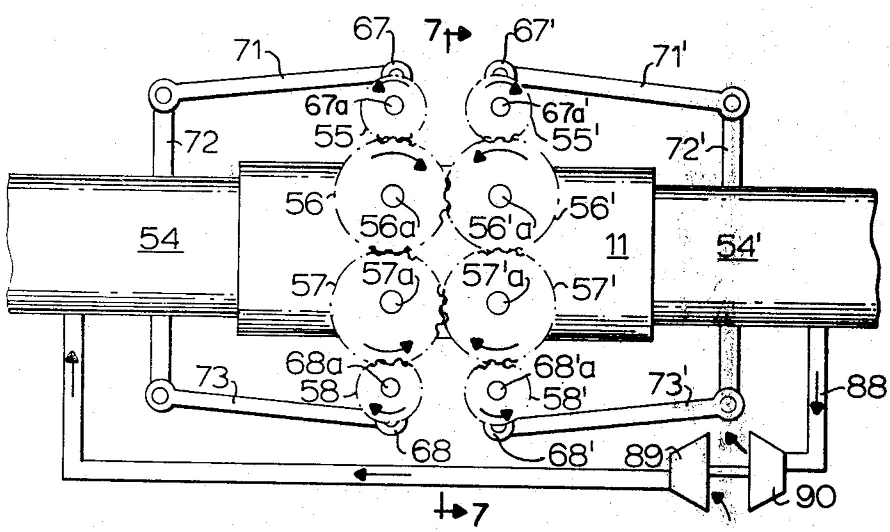
240,519	4/1946	Switzerland	123/46 R

Primary Examiner—Wendell E. Burns
Attorney, Agent, or Firm—Owen, Wickersham & Erickson

[57] **ABSTRACT**

A synchronizing device in a two-cycle piston-cylinder combination which acts as an engine to provide shaft power or, alternatively, as a gas generator to provide turbine power.

13 Claims, 8 Drawing Figures



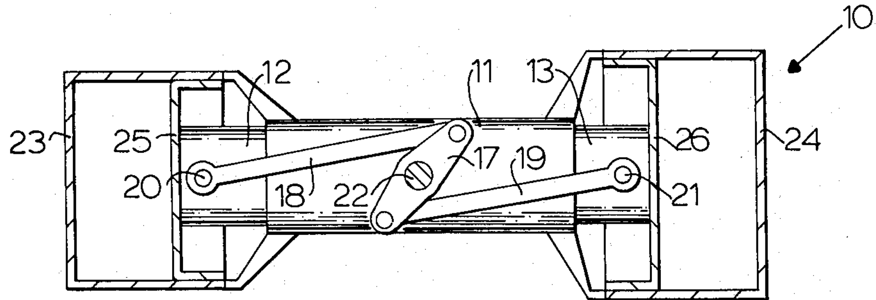


FIG. 1

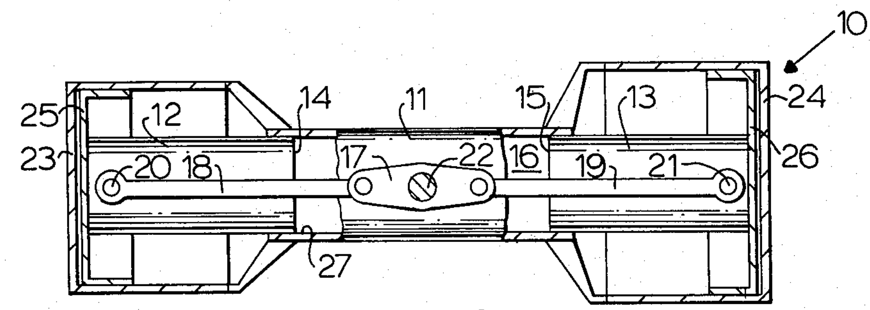


FIG. 2

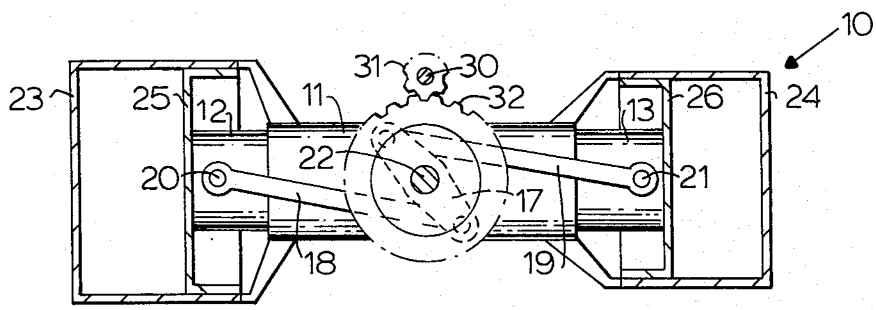


FIG. 3

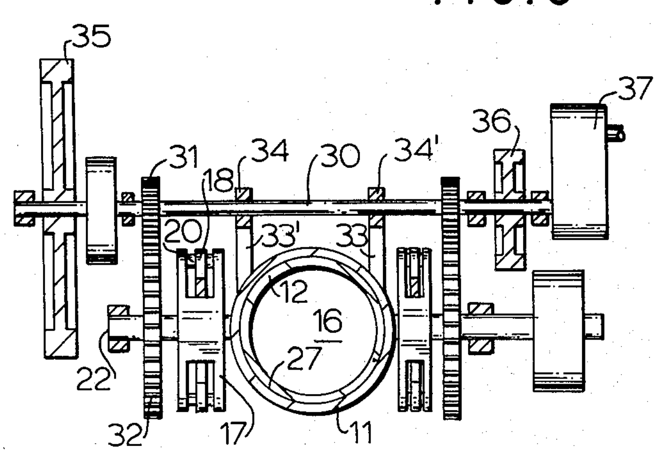


FIG. 4

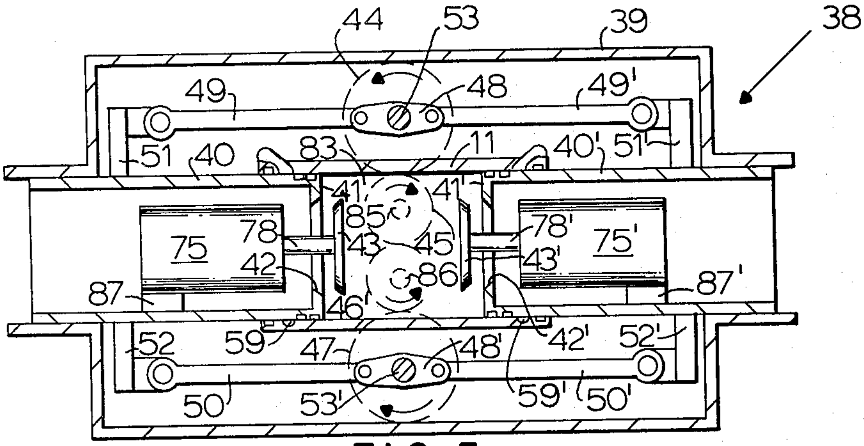


FIG.5

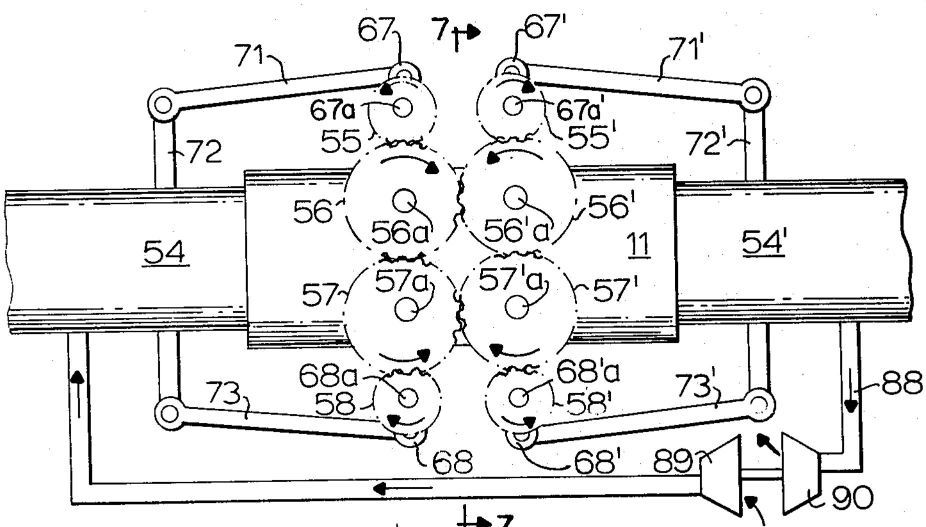


FIG.6

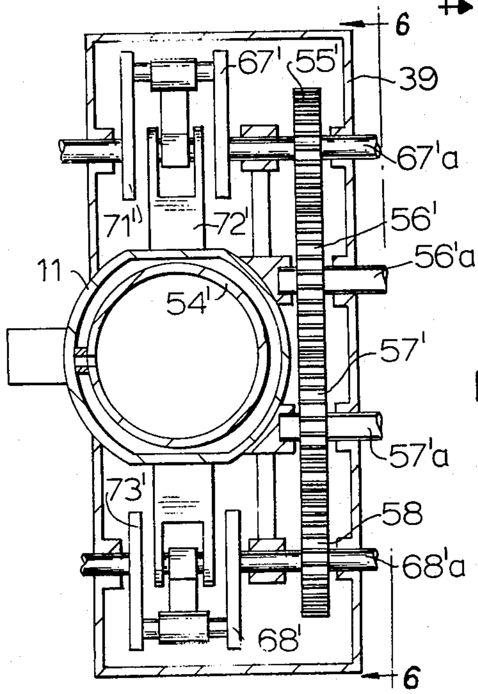


FIG.7

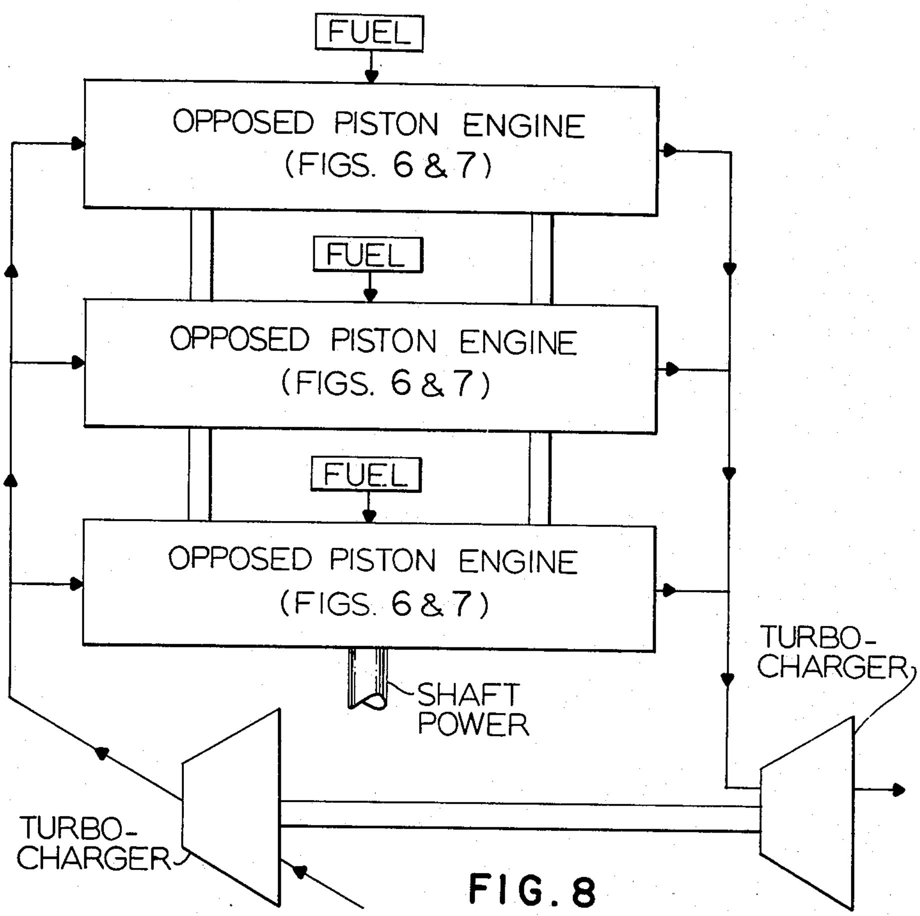

FUEL
OPPOSED PISTON ENGINE
(FIGS. 6 & 7)
FUEL
OPPOSED PISTON ENGINE
(FIGS. 6 & 7)
FUEL
OPPOSED PISTON ENGINE
(FIGS. 6 & 7)
SHAFT
POWER
TURBO-
CHARGER
TURBO-
CHARGER

FIG. 8

ENGINE AND GAS GENERATOR

This application is a division of application Ser. No. 70,387, filed Sept. 8, 1970, now U.S. Pat. 3,712,276 issued Jan. 23, 1973.

SUMMARY OF THE INVENTION

This invention relates to improvements in a two-cycle piston-cylinder combination which can act as an engine to provide shaft power or as a gas generator to provide turbine power, or which can be useful for other purposes.

Thus, one object of this invention is to eliminate the need for sleeve ports to scavenge a two-cycle engine. This novel scavenging means may be used in a single piston with a cylinder head; it can also be used in opposed-piston arrangements. For a single piston, my new engine may be scavenged and charged through the piston head by employing a valve arrangement similar to the one shown by FIGS. **7–13** of my U.S. Pat. No. 3,340,854. The improvement over that patent is an exhaust channel which may be provided inside the piston cylinder to eliminate the need for sleeve ports; thus, the piston can be lubricated and its seal rings hold the oil consumption to as low a rate as is achieved by the best four-cycle engine. Another arrangement of the single piston engine may use a combination of the cam-operated poppet-valves in the cylinder head and the inertia-operated valves in the piston head with exhaust channels inside the piston to provide larger intake and exhaust port areas than most four-cycle engines have. The opposed-piston arrangement may be provided with an intake valve in one piston and an exhaust valve in the opposite piston with an exhaust channel inside this piston. This opposed-piston arrangement will have unidirection scavenging with no oil-consuming sleeve ports.

Another feature of this invention is an improvement on the inertia-operated valve shown in my U.S. Pat. No. 3,340,854, to provide means for locking the valve closed until it approaches its crank end. For an engine with large pistons and long strokes, the inertia-operated valve is the preferred design. When the engine pistons are small and their strokes short, a valve located in the piston with a cam-opening device in the engine housing is the preferred design.

The two-cycle engine of this invention may be used to produce shaft power directly by means of a piston driven mechanism, or it may be used to generate compressed air and hot exhaust gases which may be expanded through a gas turbine to produce shaft power.

This engine or gas generator is unique in that it may employ a semi-free piston. The piston may be free to adjust the stroke for the compression ratio at the engine head end for compression ignition; however, at the crank end of its stroke, the piston may be limited by a toggle action of its oscillating crank action. The volumetric efficiency of the compressor for this semi-free compressed gas generator will be higher than the corresponding value obtained in the conventional free-piston engine.

This oscillating crank or toggle mechanism makes it possible to employ a rotating or an oscillating flywheel instead of a recoil piston to drive the engine piston to compression ignition pressures. The flywheel may be geared to rotate or oscillate at several times the frequency of the oscillating pistons, thus it will be more effective for a given mass inertia. The semi-free piston will have a wider operating speed range than a free-piston engine with a recoil piston.

In the current crank-and-rod engines there is considerable side load on the piston and cylinder walls when the high-pressure gases act on the piston during its expansion stroke. This invention uses a novel arrangement of two counter-rotating cranks and rods on each piston in an opposed-piston engine to eliminate practically all of this high side load from the piston and cylinder; thus the piston will have less drag and wear. The connecting rods and cranks are phased so that the side load is equally distributed between them and goes directly into the connecting rod and crank bearings. This unique means of eliminating side loads from pistons may also be used in my semi-free piston engine. In the semi-free piston engine with counter-oscillating levers and in the crank-and-rod engine with two counter-rotating cranks and rods on each piston, the resultant force on the rods is designed to go through the center line of the piston cylinder.

This invention describes an opposed-piston engine which is dynamically balanced, and it has little or no side loads on the piston due to pressure forces. A standard building block concept may be used to increase the power output and give more uniform torque for larger engines. For example, a standard opposed-piston engine block of this invention can produce 100 horsepower. Two such engines can be coupled together and phased 180° apart to produce 200 horsepower. Three opposed-piston engines can be coupled together and phased 120° apart to produce 300 horsepower, etc.

This invention also relates to improvements in piston gas generators.

One of the weaknesses of the free-piston gas generator is that it has to generate the full charge of compressed gas for each stroke, even at slow idling speeds when this charge is not needed. Also, the frequency range of the free-piston engine is very narrow, and it cannot operate at slow speeds as can a diesel or an Otto engine. The gas generator of this invention as well as my piston gas generator of U.S. Pat. No. 3,143,850 can be converted to simple diesel engines which idle at slow speeds and do not have to generate any high-pressure gases or low-pressure gases. My two types of gas generators, which may be converted to simple diesel engines, are more efficient than a free-piston gas generator especially for interrupted and variable speed mobile power applications such as trucks, buses, automobiles, tractors, trains, etc.

This invention also features an engine which has better thermal and combustion efficiencies than the present diesel and Otto engines. Also, because of the charging through the pistons, there will not be any blow-by gases in the engine crankcases. Thus the engine of this invention generates consideraly less smog than the present diesel and Otto engines. After-burning can be provided if desired, in the low pressure piston motor to insure complete combustion. This after-burning will heat gases that are expanded to do useful work.

BRIEF DESCRIPTION OF DRAWINGS

In the drawings:

FIG. **1** is an elevation view partly in section and partly in phantom to show the piston positions of a semi-free opposed-piston engine, according to this invention, when the pistons have reached their closest-together position and the high-pressure gases in the common cylinder force the pistons to move apart. The synchronizing mechanism is cut away.

FIG. 2 is a view like FIG. 1 with the rocker arm and connecting rods in their extending straight line toggle position to limit the outward stroke of the pistons.

FIG. 3 is a view like FIG. 1 in which the rocker arm has rocked to a position which is counter to the one shown by FIG. 1 and also showing a synchronizing gear train.

FIG. 4 is a section view taken along line 4—4 of FIG. 3, showing additionally how the gear train may be used to synchronize the rocker arms with their respective rods on the opposite sides of the engine cylinder. The rotating speed of the flywheels is highest when the rocker arms are in their straight line extended toggle position of FIG. 2; thus the flywheels may use their stored kinetic energy to force the two small pistons to compress air in their common cylinder.

FIG. 5 is a sectional horizontal view of an opposed-piston two-cycle engine having a common cylinder, two pistons therein, inlet means in one piston head and exhaust means in the other piston head, and means for sealing the piston so that the flow of oil into the engine cylinder is restricted to a minimum.

FIG. 6 is a schematic plan view of a crank-and-rod opposed-piston engine with a turbo-charger, taken on line 6—6 of FIG. 7, with both sides of the cylinder shown to include all the synchronizing gears and four crank-and-rod mechanisms to keep the large side loads off the pistons and maintain the engine in dynamic balance.

FIG. 7 is a sectional view taken on line 7—7 of FIG. 6, showing the piston drive means and other features.

FIG. 8 is a flowsheet showing a power plant arrangement including three opposed-piston engines according to this invention connected in series to power a common shaft, and including a turbo-charger to compress air feed and a turbine through which exhaust gases are discharged.

DETAILED DESCRIPTION OF THE INVENTION

In FIGS. 1 and 2 there is illustrated a semi-free opposed-piston engine **10** comprising a common cylinder **11** and opposed pistons **12** and **13** which reciprocate therein. The respective head ends **14** and **15** of these pistons are at their closest-together positions in FIG. 1, and the space **16** between these head ends is then filled with gases under compression and under high pressure. Motion of the pistons is synchronized by rocker arm **17** and connecting rods **18** and **19**, the rod **18** being pivotally affixed to the piston **13** at the pin **21**, the rocker arm **17** being pivotally affixed to a suitable support on the cylinder wall **27** at a pin **22**. There are also provided compressor cylinders **23** and **24** which receive and support cylindrical ends or bases **25** and **26** of the pistons **12** and **13**, respectively. The ends or bases **25** and **26** fit snugly and ride freely within the cylinders **23** and **24**, respectively. The kinetic energy of the oscillating flywheel described below in relation to FIG. 4 forces the pistons **12** and **13** toward each other again to compress a fresh charge of gas which may be fed in at sleeve ports or through the piston head **14** or **15** as shown in FIG. 5. It will be understood that pistons **12** and **13** of the engine of FIG. 5 are provided with wholly contained ducting means for inlet of air and exhaust of gases and to prevent contact of such gases with the lubricated surfaces between the sliding contact surfaces of the pistons **12** and **13** and the interior wall **27** of the cylinder **11**, as described elsewhere herein, but that those and other elements are omitted from FIG. 1 for a clearer showing of the rocker arm and rod means for synchronizing movements of the pistons.

The engine of FIGS. 3 and 4 is like that of FIGS. 1 and 2 but includes a showing of a gear train suitable for oscillating power take-off from the rocker arm **17**, wherein a power shaft **30** is driven by a gear **31** which in turn is driven by a gear **32** affixed to the rocker arm **17** and thus driven thereby when the expansion of the gases in the space **16** forces the arm **17** out to the position shown in FIG. 2. In the drawings, like parts are designated by like numerals. FIG. 4 is a view, partially in section, of the device of FIG. 3, showing the arrangement of the driving and power take-off mechanisms but omitting certain parts, such as the pistons, for clarity. In this view, the cylinder **11**, which is suitably supported by means not shown, supports the shaft **30** by pedestals **33, 33′** having suitable bearings **34, 34′** to receive a shaft **30**. When the rocker arm **17** is forced out by the expanded gases to the position shown in FIG. 2, the energy released can be transmitted to a large flywheel **35** for idling or to a small flywheel **36** for operating speeds (with the large flywheel **35** then declutched) and thence to a driven mechanism, e.g., through a device such as a scotch crosshead **37**, all controlled by means of conventional clutch arrangements.

FIG. 5 illustrates an opposed-piston two-cycle engine **38** according to this invention and shows the protected flow of gases therethrough, the engine **38** comprising a housing **39**, a common cylinder **11** and pistons **40** and **40′**. In each head **41, 41′** of the pistons is centrally disposed a port **42, 42′** into which a valve head **43, 43′** seats, respectively. Disposed adjacent the cylinder **11** is a gear train comprising gears **44, 45, 46** and **47**, of which the gear **44** is affixed to a shaft **53** which bears on the cylinder **11**, the other end of the shaft **53** bearing a rocker arm **48**; and the gear **47** is affixed to a shaft **53′** which bears on the cylinder **11**. The other end of the shaft **53′** is affixed to a rocker arm **48′**. Pivotally connected to the arm **48** are rods **49** and **49′**; and to the arm **48′**, rods **50** and **50′**. At their ends remote from the arm **48**, the rods **49, 49′** are pivotally connected to beams **51, 51′** attached respectively to the pistons **40, 40′**. Similarly, the rods **50, 50′** are affixed to beams **52, 52′** which are likewise affixed respectively, to the pistons **40, 40′**, so that as the arms **48, 48′** move in synchronization about their central shaft pivots **53, 53′**, the pistons **40** and **40′** reciprocate accordingly counter to each other within the cylinder **11**. Within each piston **40, 40′**, is disposed a smaller tubular body **75, 75′** concentric and integral, through spokes **87, 87′**, with the pistons **40, 40′**, and adapted to receive and guide a stem **78, 78′** attached to the valve head **43, 43′** in this embodiment. In this embodiment, the port **42** is the intake port and the port **42′** is the exhaust port. The pistons **40, 40′** are lubricated with suitable liquid oil lubricant at an annulus **59, 59′** which is sealed by rings on the pistons **40, 40′** and the cylinder **11**; and it can be seen that the path of heated exhaust gas prevents substantial contact thereof with the lubricant, thus avoiding substantial cracking or degradation of the latter.

In the operation of this engine **38**, air or an air-fuel mixture is fed through the piston **40** and its port **42** into a central space **83**. When the pistons approach their mid-inward stroke position the valves **43** and **43'** are closed and the trapped gas is compressed as the pistons **40** and **40'** move further toward each other. As the closest-together position of the heads **41** and **41'**, both of the valves **43** and **43'** are still seated in their respective ports **42** and **42'**, and the compressed gas can be combusted by conventional fuel injection (not shown) or conventional spark ignition (not shown) to generate heat and gaseous products of combustion, forcing the pistons **40** and **40'** to move apart, the valves **43** and **43'** remaining closed until the pistons **40** and **40'** approach their furthest apart position. Then the port **42'** is open to withdraw the gaseous products of combustion, which flow outward through the piston **40'** and are removed; and the port **42** opens to admit a fresh charge which scavenges the exhaust gas remaining in the space **83.** The opening of these valves **43** and **43'** will be further described later herein.

As the pistons **40** and **40'** recede from each other, the beams **51** and **51'** attached thereto, respectively, are forced away from each other and, being connected to the arms **48** and **48'** by way of the rods **49, 49', 50, 50'**, force the arms **48, 48'** to assume a position parallel to the axis of cylinder **11** at the farthest-apart position of the heads **41** and **41'**. At this time, the ports **42** and **42'** are fully open. The pistons **40** and **40'** then begin to approach each other again, actuated by the flywheel **36** shown in FIG. **4** for normal speeds. The large flywheel **35** may be clutched in for idling speeds.

As the pistons **40** and **40'** move apart as described above, and extend the arms **48** and **48'**, the gears **44** and **47** are actuated, and these in turn actuate the gears **45** and **46** which actuate, respectively, oscillating power take-off shafts **85, 86.** When the arms **48** and **48'** and the rods **49, 49'** and **50, 50'** are in their extended position the oscillating flywheel **36** is rotating at its maximum speed; thus the kinetic energy in the flywheel **36** will turn the shafts **53** and **53'** and the arms **48** and **48'** to drive the pistons **40** and **40'** together to compress another charge, the recoil action of the compressed charge absorbing the full kinetic energy of the flywheel **36.** In an advantageous embodiment the gears are, or the gear train is, adjusted so that the flywheel **36**, which is an oscillating flywheel, oscillates at a higher frequency than that of the rocker arm **48** and rod **49**, preferably several times that of the latter.

FIG. 6 is a schematic plan view of the opposed-piston crank-and-rod engine shown in FIG. **7**, FIG. **7** being taken on line **7—7** of FIG. **6**, such engine comprising the engine housing **39**, the common cylinder **11**, opposed pistons **54, 54'**, gears **55, 56, 57, 58** and **55', 56', 57'** and **58'**; and rods **71, 71'** and **73, 73'**, pivotally attached to, respectively, beams **72** and **72'** at one end of each such rod and to cranks **67, 68, 67'** and **68'**, respectively, at the other end of each such rod. In an exhaust line **88** from the piston **54** are disposed turbochargers **89** and **90.** The crank **67** and the gear **55** are fixed to a shaft **67***a*. The crank **68** and the gear **58** are fixed to a shaft **68***a*. The gear **56** is keyed to a shaft **56***a* and the gear **57** is keyed to a shaft **57***a*. The shafts **67***a*, **56***a*, **57***a* and **68***a* have their bearings on the engine housing **39**, and each can be used to transmit power. In like manner, the crank **67'** and the gear **55'** are fixed to the shaft **67'***a*, and the crank **68'** and the gear **58'** are fixed to the shaft **68'***a*; the gears **56'** and **57'** are keyed to the shafts **56'***a* and **57'***a*, respectively; and such shafts have their bearings on the engine housing **39**, and each shaft can be used to transmit rotating shaft power in one direction.

FIG. **8** is a flowsheet showing as an example an arrangement comprising of crank-and-rod building block engines where three opposed piston engines as indicated operate a common rotating shaft for power in one prescribed direction of rotation, and gaseous exhaust products are fed through the turbine of a turbocharger to operate the supercharger which provides compressed air to the engine intake.

The above specific description and the drawings have been given for purposes of illustration and variations and modifications can be made therein without departing from the spirit and scope of the appended claims. Where an element is described as pinned to another element, it will be understood that such element is pivotally attached thereto.

Having now described the invention, I claim:

1. In an opposed-piston engine including a first piston, a second piston, a cylinder having first and second ends, each said piston having a sliding surface engaging said cylinder, said pistons having facing heads and opposite ends distant from said heads, and means to introduce gas and air into said cylinder, said pistons being adapted to reciprocate toward and apart from each other in said cylinder, the improvement comprising:

synchronizing means for causing said pistons to reciprocate and comprising

four crankshafts centrally and symmetrically located near said head end and having cranks thereon and two single-branched connecting rods for each piston, each said connecting rod being connected respectively to a separate said crankshaft, the midsections of said cranks and rods being positioned to move in the same plane, and symmetrically located with respect to said synchronizing means,

means for causing said crankshafts to cause said pistons to reciprocate in opposite directions to each other so that said pistons and synchronizing mechanism are dynamically balanced.

2. The engine of claim **1** wherein said last-named means for causing comprises a gear train joined to each said crankshaft and in driving relation therewith.

3. A dynamically balanced opposed-piston engine exhibiting minimal side loads on its pistons in operation, having a first piston, a second piston, a common cylinder for said pistons, a common centrally located combustion chamber, and synchronizing means comprising:

a. a first said connecting rod pivotally affixed to said first piston at one end and to a first crank at its other end,

b. a second connecting rod pivotally affixed to said first piston at one end and at its other end to a second crank,

c. a third connecting rod pivotally affixed at one end to said second piston and at its other end to a third crank,

d. a fourth connecting rod pivotally affixed at one end to said second piston and at its other end to a fourth crank,

e. said first and second cranks rotating counter to each other when in operation,

f. said third and fourth cranks rotating counter to each other when in operation,

g. said first and third cranks being located adjacent to each other and rotating counter to each other when in operation,

h. said second and fourth cranks being located adjacent to each other and rotating counter to each other when in operation,

i. said first and fourth cranks being located diagonally with respect to each other and rotating in the same direction and said second and third cranks being located diagonally with respect to each other, and rotating in the same direction,

j. all said cranks being positioned symmetrically to each other with respect to a center point of said common cylinder,

k. a separate crankshaft affixed to each said crank, all said crankshafts rotating at the same speed,

l. all said connecting rods lying in and moving in a single plane, which plane also includes the centerline of said common cylinder.

4. A dynamically balanced opposed piston engine combination comprising a plurality of the engines of claim **3** connected in series and wherein

said crankshafts are so connected together that the combustion cycle of each engine is equi-angularly out of phase with each other of said engines to provide more uniform shaft power.

5. Combination as in claim **4** wherein two of said engines are so connected and said combustion cycles are 180° out of phase.

6. Combination as in claim **4** wherein three of said engines are so connected and said combustion cycle is 120° out of phase.

7. The engine of claim **3** wherein all four said connecting rods are identical and interchangeable members.

8. The engine of claim **3** wherein all four of said cranks are identical and interchangeable and all four of said crankshafts are identical and interchangeable.

9. The engine of claim **3** wherein said first and second pistons are identical and interchangeable.

10. An engine as in claim **1** being dynamically balanced and exhibiting minimal side loads on said pistons when in operation and wherein said synchronizing means comprises:

a. a first connecting rod pivotally affixed at one end to said first piston and to a first rocker arm at its other end,

b. a second connecting rod pivotally affixed at one end to said second piston and at its other end to said first rocker arm at its other end,

c. a third connecting rod pivotally connected to said first piston at one end and to a second rocker arm at its other end, and

d. a fourth connecting rod pivotally affixed at one end to said second piston and at its other end to said second rocker arm whereby said second piston is adapted to reciprocate counter to said first piston in operation,

e. said first and second rocker arms being positioned to rock in the same plane and being adapted to rock counter to each other to minimize said side forces.

11. An internal combustion engine comprising in combination:

a. an engine cylinder having a wall and a head end,

b. means to introduce gas into said cylinder,

c. an engine piston adapted to reciprocate in said cylinder and to compress said gas therein, said gas then limiting the stroke of said piston toward said head end,

d. a first rocker arm,

e. a first connecting rod extending generally in the same direction as said cylinder and connecting said piston and said first rocker arm to form an extended toggle to limit the stroke of said piston in a first direction,

f. a second rocker arm, and

g. a second connecting rod extending generally in the same direction as said cylinder and connecting said piston and said second rocker arm to form an extended toggle to limit the stroke of said piston in said first direction,

h. said first and second rocker arms being positioned to rock in the same plane and being synchronized to rock counter to each other, said plane also including the centerline of said cylinder, whereby toggle link forces on said first and second connecting rods normal to said cylinder wall are balanced on said toggle links to prevent high side forces from acting on said cylinder.

12. An engine comprising:

a. a cylinder,

b. a first piston and a second piston adapted to reciprocate therein counter to each other,

c. a first connecting rod affixed at one end to said first piston and at its other end to a first crank,

d. a second connecting rod affixed to said first piston at one end at its other end to a second crank,

e. a third connecting rod affixed at one end to said second piston and at its other end to a third crank,

f. a fourth connecting rod affixed at one end to said second piston and at its other end to a fourth crank,

g. said cranks all being positioned to rotate in the same plane,

h. said first and second cranks being synchronized to rotate counter to each other and said third and fourth cranks being synchronized to rotate counter to each other, whereby the respective connecting rod forces acting normal to said cylinder will be balanced in operation,

i. said first and second and said third and fourth cranks being so synchronized that said first and second pistons reciprocate to each other.

13. An engine comprising:

a. a cylinder,

b. a first piston and a second piston adapted to reciprocate therein counter to each other,

c. a first connecting rod affixed at one end to said first piston and at its other end to a first crank,

d. a second connecting rod affixed to said first piston at one end and at its other end to a second crank,

e. a third connecting rod affixed at one end to said second piston and at its other end to a third crank,

f. a fourth connecting rod affixed at one end to said second piston and at its other end to a fourth crank,

g. said connecting rods and said cranks all being positioned to move in the same plane,

h. said first and second cranks being synchronized to move counter to each other and said third and fourth cranks being synchronized to move counter to each other, whereby the respective connecting rod forces acting normal to said cylinder will be balanced in operation,

i. said first and second and said third and fourth cranks being so synchronized that said first and second pistons reciprocate counter to each other.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,895,620

DATED : July 22, 1975

INVENTOR(S) : Berry W. Foster

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 53, after "to the piston" insert --12 at a pin 20 and the rod 19 being pivotally affixed to the piston--.

Column 5, line 3, "As" should read --At--.

Column 6, line 4, after "comprising" insert --a plurality--.

Column 8, line 28, which is line 8 of claim 12, "at its other" should read --and at its other--.

Column 8, line 43, which is the last line of claim 12, after "reciprocate" insert --counter--.

Signed and Sealed this

twenty-eight Day of *October 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks