60-280. OR 3,180,078 SR

SEARCH ROOM

April 27, 1965 J. LISTON 3,180,078

COMBINED INTERNAL COMBUSTION AND HOT-AIR ENGINE

Filed April 14, 1961 3 Sheets-Sheet 1

Fig. 1

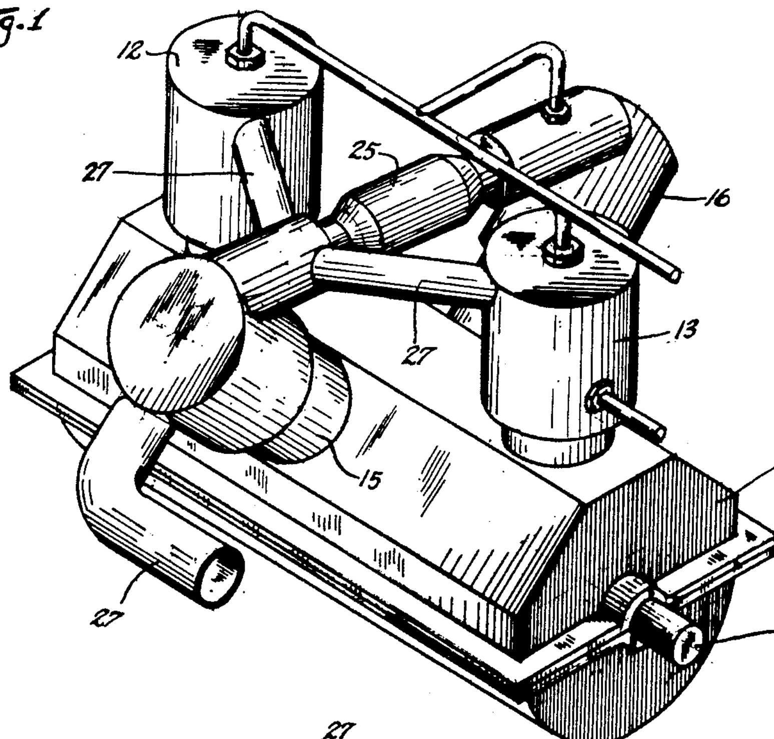
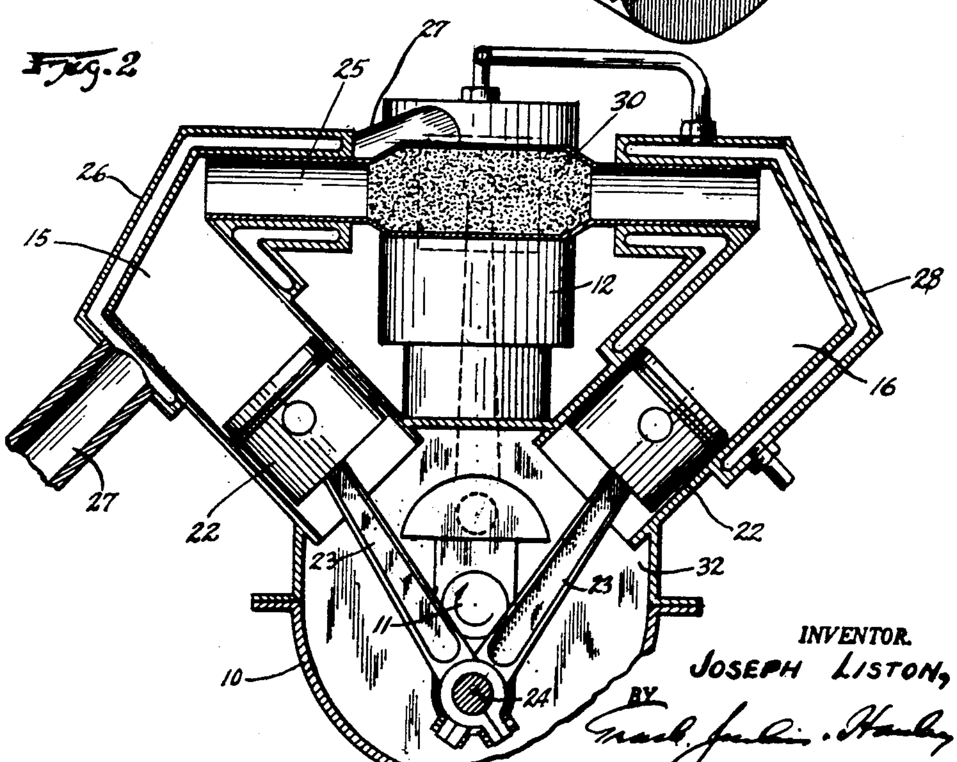


Fig. 2



INVENTOR.
JOSEPH LISTON,
BY
ATTORNEYS.

COMBINED INTERNAL COMBUSTION AND HOT-AIR ENGINE

Filed April 14, 1961

3 Sheets-Sheet 2

Fig. 3

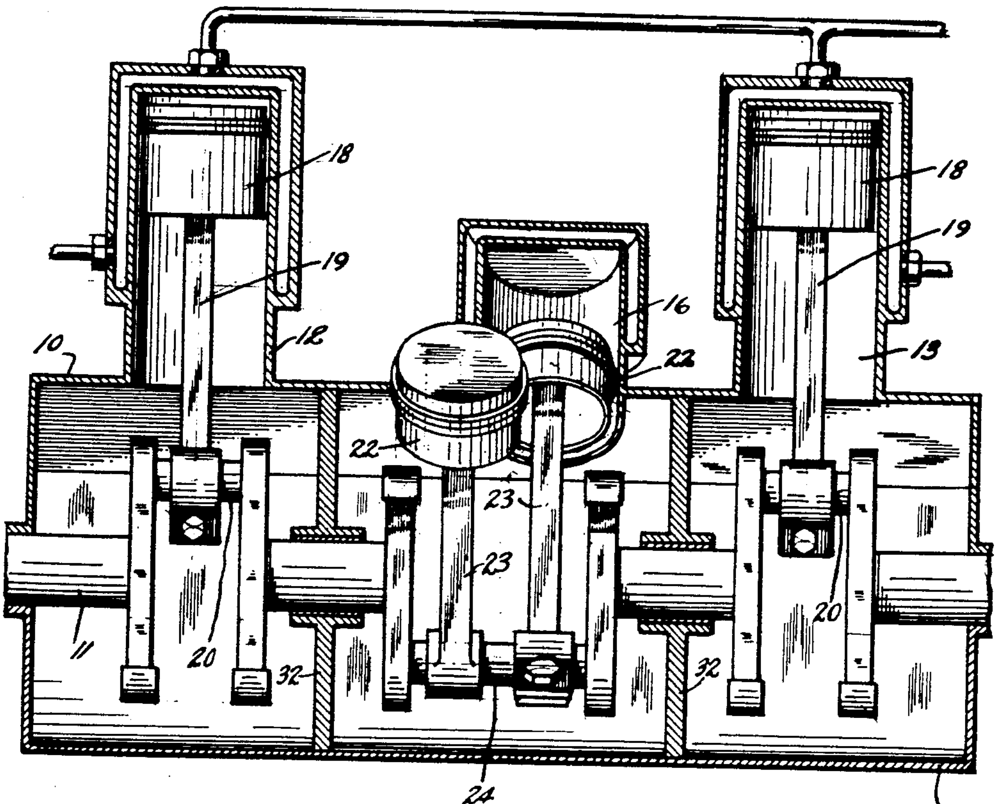
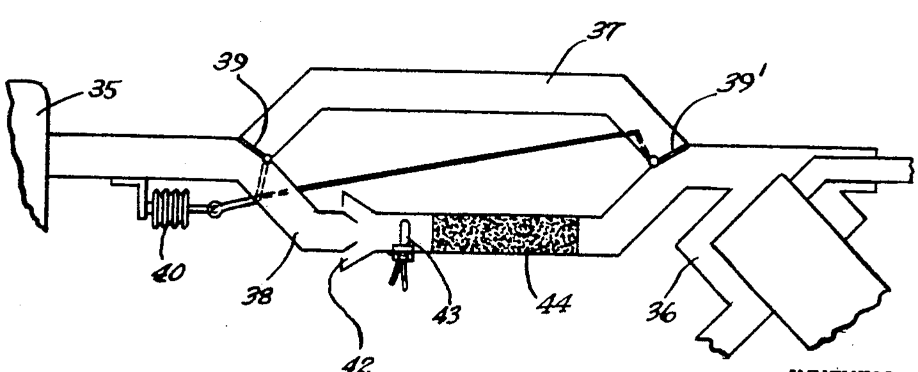
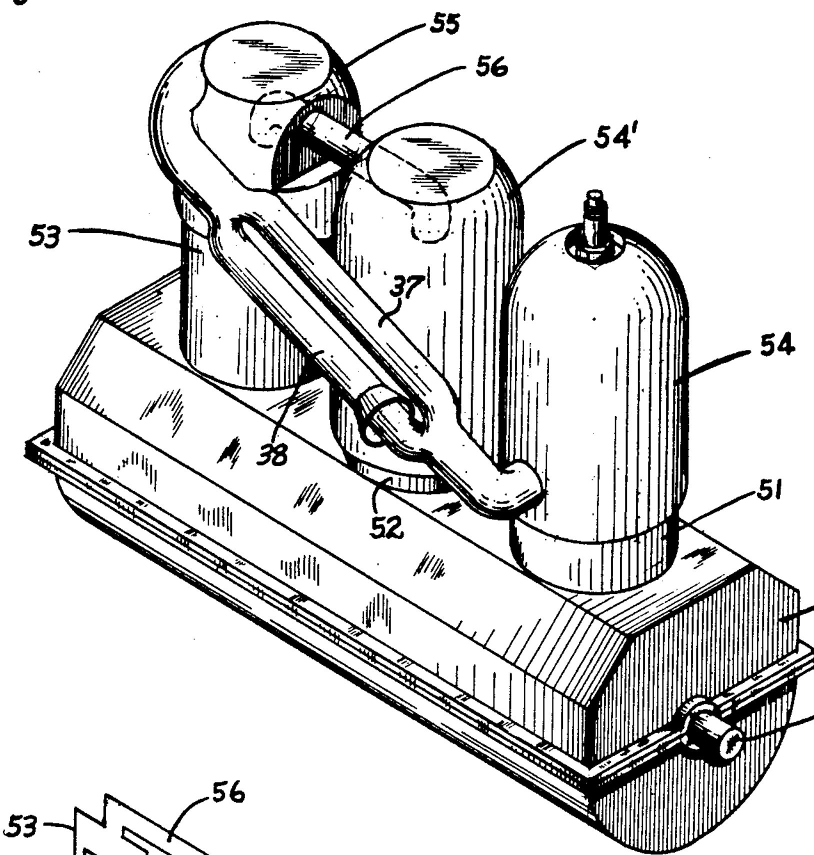


Fig. 4



INVENTOR.
JOSEPH LISTON,
BY
ATTORNEYS.

Fig. 5



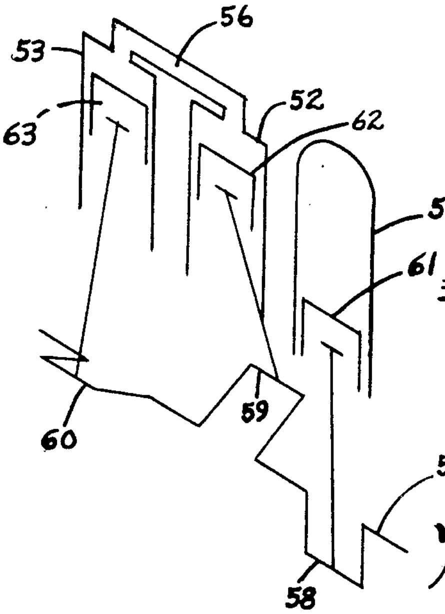


Fig. 6

INVENTOR.
JOSEPH LISTON,
BY
[signature]
ATTORNEYS.

United States Patent Office

3,180,078

Patented Apr. 27, 1965

1

3,180,078

COMBINED INTERNAL COMBUSTION AND HOT-AIR ENGINE

Joseph Liston, Lafayette, Ind.
(900 Robinson St., West Lafayette, Ind.)

Filed Apr. 14, 1961, Ser. No. 103,044
4 Claims. (Cl. 60—14)

The subject matter of this invention is a two-stage power plant or prime mover, the first stage of which is an internal combustion engine and the second stage of which is a hot-air or Stirling-cycle engine operated by heat derived from the gases exhausted by the first stage. An arrangement heretofore proposed for utilizing in a Stirling engine heat contained in the exhaust gases from an internal combustion engine employed a cylinder and piston combination in which the head-end of the cylinder functioned as a combustion space, as in an ordinary internal combustion engine, and the crank-end of the cylinder functioned as the cold space of a Stirling engine. In that arrangement, inward movement of the piston under pressure generated by combustion compressed the gaseous working medium of the Stirling engine and displaced it into a heat-exchanger where it absorbed heat from the gases exhausted from the head-end of the cylinder. After bottom dead-center, the compressed and heated working medium expanded into the crank-end of the cylinder impelling the piston outwardly. Such an arrangement has several disadvantages. In the first place, there is an inevitable and undesirable transfer of heat from the combustion space to the Stirling-engine cold space by conduction through the piston and cylinder wall. In the second place, it is desirable that the fixed quantity of working medium employed in the Stirling engine be maintained under substantial pressure, and the low fluid pressures which would exist in the combustion space just before compression and during the initial stages thereof would contribute to the escape of the working medium past the piston. Again, since a single piston is used, variation in the displacements of the two engines could be obtained only by employing a piston and cylinder each having portions of different diameter, which would result in complicating the construction, increasing cost, and increasing the weight of the piston. Still further, a reasonably uniform distribution of torque impulses would be obtained only if the head-end of the cylinder operated on a two-stroke cycle, for a Stirling engine delivers a torque impulse for each revolution of the crankshaft.

It is an object of this invention to produce a prime mover having an internal-combustion engine as a first stage and a Stirling engine as a second stage and to utilize in the Stirling engine the heat contained in or derivable from the exhaust gases of the internal-combustion engine. Another object of the invention is to make available for use in the Stirling engine heat derived from the combustion of unburned fuel contained in the exhaust from the internal-combustion engine.

According to one feature of the present invention, the pistons and cylinders of the two stages are independent of each other, although the pistons are preferably operatively interconnected, most desirably by being associated with a common crankshaft. Operatively interconnecting the pistons of the two stages makes possible a predetermined distribution of torque impulses; and by properly arranging the cylinders of the two engines, the distribution of torque impulses can be made substantially uniform.

In accordance with another feature of my invention, I provide, in the conduit through which exhaust gases from the first stage flow to the second stage, means for burning any fuel unburned in the first stage.

Other objects and features of my invention will become

2

apparent from the following more detailed description and from the accompanying drawings in which:

FIG. 1 is an isometric view, largely diagrammatic in character, of a two-stage power plant wherein the Stirling engine is a two-cylinder, V-type engine disposed in the region between the cylinders of a two-cylinder, in-line internal combustion engine of the four-stroke cycle type;

FIG. 2 is a section through the two cylinders of the Stirling engine incorporated in the power plant of FIG. 1;

FIG. 3 is a longitudinal section through the same power plant in the plane of the cylinders of the internal-combustion engine;

FIG. 4 is a diagrammatic view illustrating means for burning fuel unburned in the internal-combustion engine;

FIG. 5 is an isometric view somewhat diagrammatic in character, of a power plant embodying the invention and employing a single-cylinder, two-stroke cycle internal combustion engine as a first stage; and

FIG. 6 is a diagrammatic view illustrating the form of a crankshaft for the power plant of FIG. 5.

The engine shown in FIGS. 1–3 comprises a crankcase **10** within which a crankshaft **11** is rotatably supported. Two cylinders **12** and **13** of an internal combustion engine are mounted on the crankcase near the ends thereof and in a common plane. Between the two cylinders **12** and **13**, the crankcase supports two cylinders **15** and **16** of a Stirling engine, such two cylinders being disposed at an angle to each other and symmetrically with respect to the common plane of the cylinders **12** and **13**. The cylinders **12** and **13** contain pistons **18** connected by connecting rods **19** to cranks **20** of the crankshaft **11**, such cranks being coaxial with each other. The cylinders **15** and **16** contain pistons **22** connected by connecting rods **23** with a common crank **24** coplanar with but diametrically opposite the cranks **20**.

The head ends of the two cylinders **15** and **16** are interconnected by a transfer conduit **25** through which the gas trapped above the pistons **22**, which gas constitutes the working medium of the Stirling engine, is transferred back and forth between the cylinders as the crankshaft rotates. As shown, the cylinder **15** constitutes the hot space of the Stirling engine, and it, together with the adjacent end of the conduit **25**, is provided with a jacket **26** connected through conduits **27** with the exhaust ports (not shown) of the cylinders **12** and **13**. The jacket **26** has an outlet opening communicating with an exhaust pipe **27**.

The cylinder **16**, which constitutes the cold space of the Stirling engine shown, is provided with a coolant jacket **28**, which desirably surrounds the adjacent end of the conduit **25** as well as the cylinder **16**. The jacket **28** may be embodied in the same coolant circulating system as that used to cool the first-stage cylinders **12** and **13**; but if so, the jacket **28** should desirably receive cold coolant directly from the radiator so as to maintain the cylinder **16** as cool as possible.

Ideally, a Stirling engine operates on a cycle in which the working medium is successively compressed isotherr ally to minimum volume, heated at the minimum volume, permitted to expand isothermally to maximum volume while doing work, and then cooled at the maximum volume. In an actual engine, there is more or less overlapping of successive steps of the cycle, the extent of such overlapping depending on the particular design of the engine. The Stirling engine shown by way of example in the drawings, provides considerable overlapping of successive cycle-steps, but it possesses several advantages which tend to compensate for such loss in efficiency as results from the overlapping. As shown in FIG. 2, the crank **24** is at the lowermost point of its path of travel, the working medium trapped above the pistons **22** has its maximum volume, and the engine has therefore just completed its working stroke. Compression of the working medium will occur as the crank **24** moves from its lowermost position to its uppermost position, when the working stroke and expansion of the working medium will begin. As will be clear from FIG. 2, where the crankshaft is indicated as rotating in a clockwise direction, movement of the crank **24** from its lowermost position will be accompanied by outward movement (relative to the crankshaft) of the piston in cylinder **15** and inward movement of the piston in cylinder **16**, and a displacement of the working medium toward the cooled cylinder will therefore result. Such displacement will continue for approximately one-fourth of a revolution, or until the time when the piston in cylinder **16** will have reversed its direction and accelerated to an outward velocity which equals and begins to exceed that of the decelerating piston in cylinder **15**. Thereafter, the displacement of the working medium will be in the general direction of the heated space of the engine, and such displacement will continue for about one-half a revolution, when both pistons will be moving inwardly and the piston in cylinder **16** attains an inward velocity which equals and begins to exceeds that of the piston in cylinder **15**, whereupon the displacement of the working medium will be reversed. It is thus apparent that in the Stirling engine shown the working medium will be heated during the last stage of its compression and the first stage of its expansion and cooled during the final stage of its expansion and the initial stage of its compression.

The efficiency of a Stirling engine can be increased by providing a regenerator or heat sink in the passage through which the working medium flows between the hot and cold spaces of the engine. Such a regenerator, indicated by the reference numeral **30**, is shown in FIG. 2 in the transfer conduit **25**. The regenerator may be any means which possesses adequate thermal capacity and a relatively large surface area and which offers little obstruction to the flow of gas through the conduit **25**. A mass of metal wool or a series of juxtaposed disks of fine-wire mesh constitutes a suitable regenerator.

The specific power plant illustrated in the drawings has several advantages, especially where the internal combustion engine is of the four-stroke cycle type and has two cylinders. Locating the Stirling engine, or at least the hot-space thereof, between two cylinders of the internal combustion engine facilitates the ducting through which the exhaust from the internal-combustion engine is conducted to such hot space. If, the two four-cycle cylinders **12** and **13** are arranged to fire alternately, the power plant provides a substantially uniform distribution of the torque impulses, the torque impulses of the Stirling engine, which occur at one-revolution intervals, alternating with the torque impulses of the two-cylinder internal-combustion engine, which in combination likewise occur at one-revolution intervals. Further, the exhaust strokes of the internal-combustion cylinders coincide approximately with the intervals in which the working medium of the Stirling engine is to be heated. The primary inertia forces of the reciprocating parts produce no substantial rocking couples and can be effectively suppressed by the employment of appropriate counterweights on the crankshaft.

For known reasons, it is desirable that the gaseous working medium of a Stirling engine be maintained under a substantial pressure, and to lessen the possibility of the escape of the working medium past the pistons, as well as for other reasons, it is desirable to maintain the inner faces of the pistons under fluid pressure comparable to the average pressure of the working medium. I have therefore shown (FIG. 3) the crankcase **10** as provided with spaced partitions **32** which are located on opposite sides of the crank **24** and which cooperate with the pistons and the walls of the crankcase to define an enclosed space the gas in which may be maintained under appropriate pressure in any convenient manner.

In an internal-combustion engine operating under varying speeds and loads, wide variations occur in the temperature of the exhaust gases; and when the exhaust gases are used to heat the hot space of a Stirling engine, the output of the latter engine will vary with the temperature of the exhaust gases. Low-temperature exhaust gases from an internal combustion engine normally contain a substantial amount of unburned fuel which, in accordance with my invention, I employ to raise the temperature that otherwise would exist in the hot space of the Stirling engine. One arrangement for accomplishing that purpose is indicated diagrammatically in FIG. 4, where the exhaust gases from an internal combustion engine **35** are shown as being conducted to the hot-space jacket **36** of a Stirling engine through a conduit having two branches **37** and **38**. Flap valves **39** and **39′** located at the junctions of the two branches **37** and **38** are employed to open one branch and close the other. Such flap valves may be operated automatically by means **40** responsive to the temperature of the exhaust gases leaving the internal combustion engine **35**. When the temperature of the exhaust gases is relatively low, the valves **39** and **39′** are positioned as shown to direct flow through the branch **38** which contains means for burning any unburned components in the exhaust gases. As shown, the branch **38** has an opening **42** for admitting the auxiliary air necessary to combustion and is also provided with an igniter **43**, which may be a simple glow plug. In addition to the auxiliary air opening and igniter, or as an alternative for the igniter, the branch **38** contains a mass **44** of an oxidation catalyst. Most oxidation catalysts which have been used to promote the combustion of unburned components in exhaust gases operate most effectively at relatively high temperatures; and while such a catalyst may eventually attain an effective temperature as a result of the combustion it induces, the use of an igniter **43** to initiate combustion and promote rapid rise in the temperature of the catalyst **44** is usually desirable.

If the internal combustion engine **35** of FIG. 4 is operating under conditions which result in high exhaust-gas temperature and substantially complete fuel consumption, the temperature-responsive means **40** will swing the valves **39** and **39′** to close the branch **38** and open the branch **37**, which provides free passage of the exhaust to the hot-space jacket **36** of the Stirling engine. By-passing of high-temperature gases around the auxiliary air-opening **42** and the catalyst **44** avoids their dilution and cooling by air which would enter through the opening **42**.

FIGS. 5 and 6 illustrate a power plant embodying the invention and suitable for incorporation of a single-cylinder two-stroke cycle internal combustion engine. Such power plant comprises a crankcase **50** supporting in coplanar relationship an internal combustion cylinder **51** and the two cylinders **52** and **53** of a Stirling-cycle engine. The cylinders **51** and **52** are provided respectively with coolant jackets **54** and **54′**, while the cylinder **53** is provided with a jacket **55** to which the exhaust from the cylinder **51** is conveyed through the branched conduit **37–38** of FIG. 4. The two Stirling-cycle cylinders are interconnected at their head-ends by a transfer conduit **56**.

The power plant shown in FIG. 5 conveniently embodies a crankshaft **57** of the form shown diagrammatically in FIG. 6. Such crankshaft has cranks **58**, **59**, and **60** connected respectively through connecting rods to the pistons **61**, **62**, and **63** in the cylinders **51**, **52**, and **53**. The cranks are arranged at equal angular intervals about the axis of the crankshaft **57**, with the crank **59** leading and the crank **60** trailing the crank **58** in rotation in the contemplated direction, which is the counterclockwise direction as indicated by the arrow in FIG. 6.

Like the crankcase **10** of FIGS. 1–4, and for the same purpose, the crankcase **50** of FIG. 5 may be divided internally by partition means to provide a pressurized chamber with which the inner ends of the cylinders **52** and **53** communicate.

In the crankshaft position shown in FIG. 6, the piston **61** in the cylinder **51** has just completed its power stroke and the working medium of the Stirling engine is at minimum volume. During the approximately 90° of crankshaft rotation prior to attainment of the crankshaft position indicated in FIG. 6, the working medium of the Stirling engine was being displaced from the cold cylinder **52** to the hot cylinder **53**, and displacement in that sense will continue for approximately an additional 90° of crankshaft rotation, whereupon the flow of the working medium will be reversed and displacement from the hot cylinder to the cold cylinder will occur. As the heated working medium begins to expand following attainment of the crankshaft position shown in FIG. 6, it will perform work on the piston **63** with the result that a torque impulse will be imposed on the crank **60**. During the working stroke of the piston **63** the piston **61** will be compressing the charge in the cylinder **51**. Charge-compression will be completed after 180° of crankshaft revolution from the position shown in FIG. 6 at which time the working medium of the Stirling engine will have attained its maximum volume.

It will thus be obvious that in the power plant of FIGS. 5 and 6 the respective torque impulses of the two-stroke cycle internal combustion engine **51** and of the Stirling engine will be substantially equally spaced. By suitable coordination of the throws of the cranks **58, 59,** and **60** and the masses of the pistons **61, 62,** and **63,** primary and secondary inertia forces can be balanced.

It may be noted that in its broad aspect the invention of this application is not limited to any particular form or type for the internal combustion engine or the Stirling engine. The two arrangements shown for purposes of illustrating the invention have certain advantages is respect to simplicity of construction, economy of manufacture, and dynamic balance, as well as other advantages. The arrangements of the cylinders of a two-cylinder Stirling engine in a common plane, as in FIGS. 5 and 6, or perpendicularly to each other, as shown in FIGS. 1–3, may not be the optimum arrangement from the standpoint of Stirling-engine efficiency; and if so, it would be possible to improve the efficiency of the Stirling engine by altering the effective angle between its two cylinders. Any such improvement, however, would be obtained at the expense of complicating the problem of balancing inertia forces.

I claim as my invention:

1. A two-stage power plant comprising an internal-combustion engine as a first stage and a Stirling-cycle engine as a second stage, said two engines having a common crankshaft, said Stirling engine having means providing intercommunicating heated and cooled chambers and including a cylinder and a piston reciprocable in the cylinder for confining a body of gaseous working medium, said internal-combustion engine including at least one cylinder and a piston reciprocable therein, said crankshaft having a separate crank for each of said cylinders, connecting rods operatively interconnecting said cranks

respectively with said pistons, ducting for conveying exhaust gases from the internal-combustion engine into heat transferring relation to said heated chamber, and means located in said ducting for burning unburned components of said exhaust gases.

2. A two stage power plant, comprising an internal-combustion engine as a first stage and a Stirling-cycle engine as a second stage, said internal-combustion engine being of the four-stroke cycle type and including two coplanar cylinders, said Stirling-cycle engine having a pair of cylinders disposed between the two internal-combustion engine cylinders and arranged at an angle to each other generally symmetrically relative to the common plane of the internal-combustion engine cylinders, a piston in each of said cylinders, a common crankshaft for the two engines, said crankshaft having two coaxial end cranks connected by connecting rods to the pistons in the internal-combustion engine cylinders and an intermediate crank spaced substantially 180° from said end cranks and connected by connecting rods to the pistons in the cylinders of the Stirling-cycle engine, a transfer conduit interconnecting the head ends of the latter cylinders, a jacket for one of the cylinders of the Stirling-cycle engine, ducting for conveying exhaust gases to said jacket from the cylinders of the internal-combustion engine, means located in said ducting for burning unburned components of said exhaust gases and means for cooling the other cylinder of the Stirling-cycle engine.

3. A two stage power plant, comprising an internal-combustion engine as a first stage and a Stirling-cycle engine as a second stage, said Stirling-cycle engine comprising two cylinders and a transfer conduit interconnecting their head ends, pistons in said cylinders, said internal-combustion engine being of the two-stroke cycle type and having a single cylinder containing a piston, all three of said cylinders being at least approximately coplanar, a common crankshaft for said engines, said crankshaft having three cranks spaced at substantially equal angular intervals about the crankshaft axis and connected by connecting rods to the three pistons respectively, one of said Stirling-engine cylinders being provided with a jacket, ducting for conveying exhaust gases from the internal-combustion engine to said jacket, and means located in said ducting for burning unburned components of said exhaust gases.

4. A power plant as set forth in claim 3 with the addition that said internal-combustion engine cylinder and said jacketed cylinder of the Stirling-engine are located on opposite sides of the other Stirling-engine cylinder.

References Cited by the Examiner

UNITED STATES PATENTS

2,196,979	4/40	Campbell	60—14
2,590,519	3/52	Du Pre	60—24
2,616,250	11/52	Yzer	60—24
2,907,169	10/59	Newton	60—24

EDGAR W. GEOGHEGAN, *Primary Examiner.*

SAMUEL LEVINE, ROBERT R. BUNEVICH, JULIUS E. WEST, *Examiners.*