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STIRLING CYCLE ENGINE WITH WAVE-CAM MEANS INTERCONNECTING PISTONS AND DRIVE SHAFT THEREOF

Filed Dec. 9, 1966 4 Sheets-Sheet 1

Fig 1

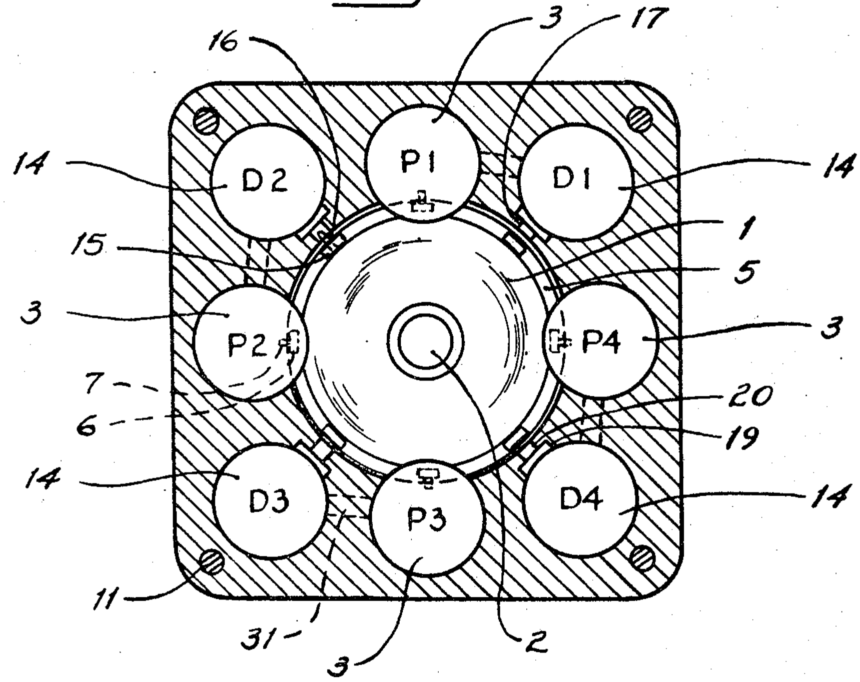

Fig. 2

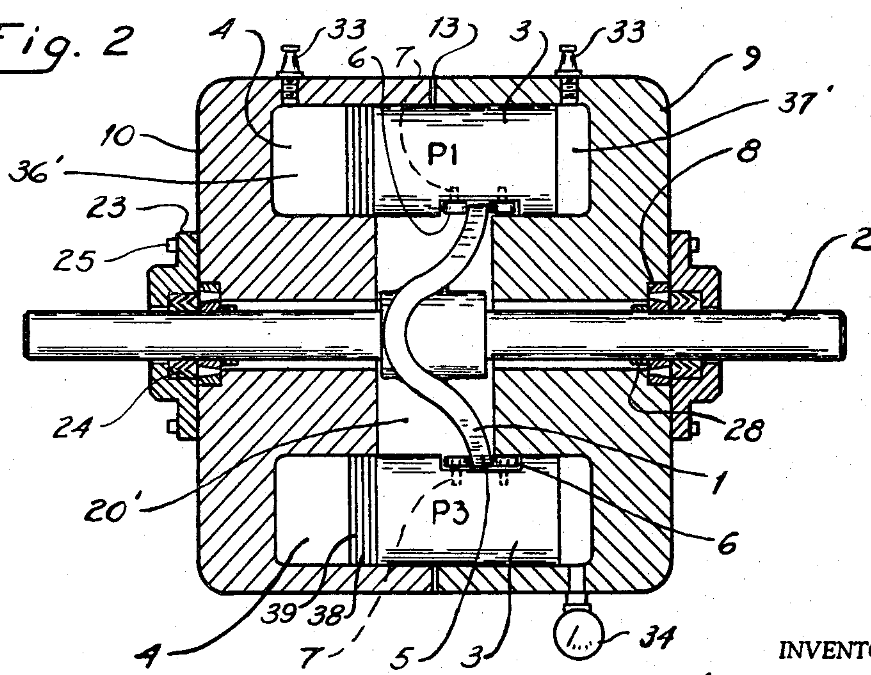

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Fig. 3

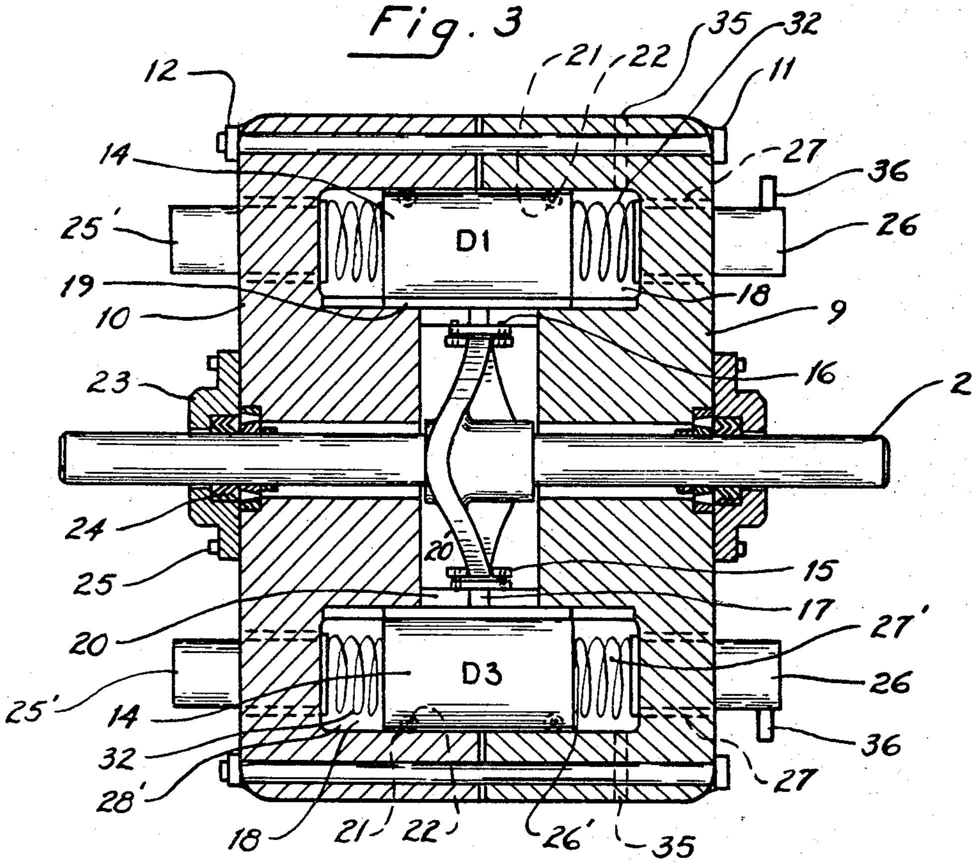
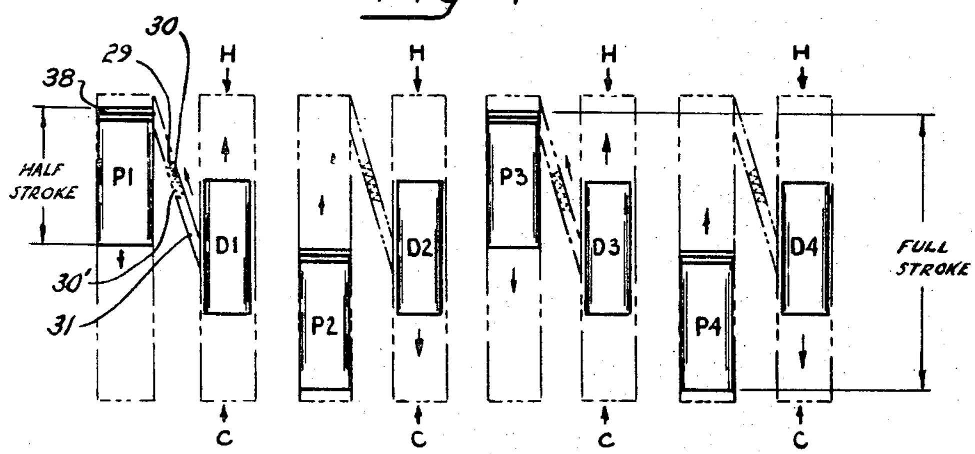


Fig 4



PHASE DIAGRAM

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Fig. 5

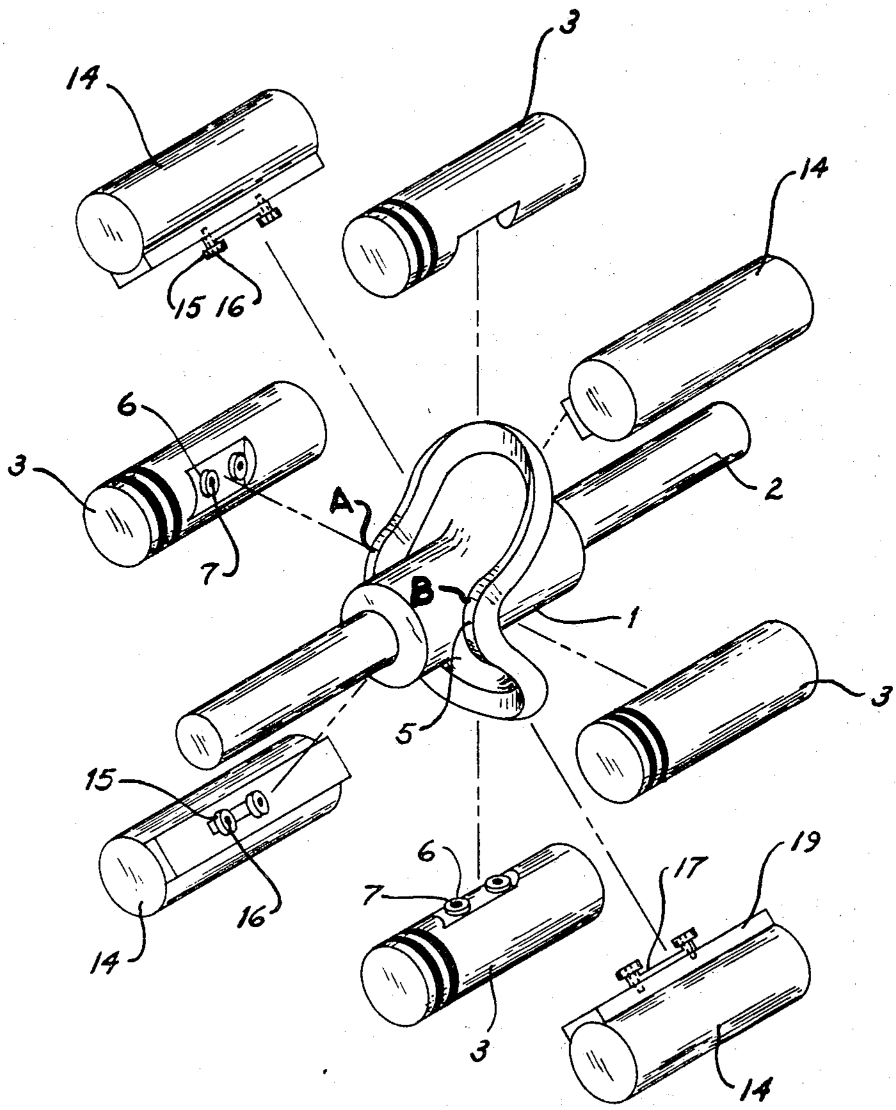

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Fig. 6

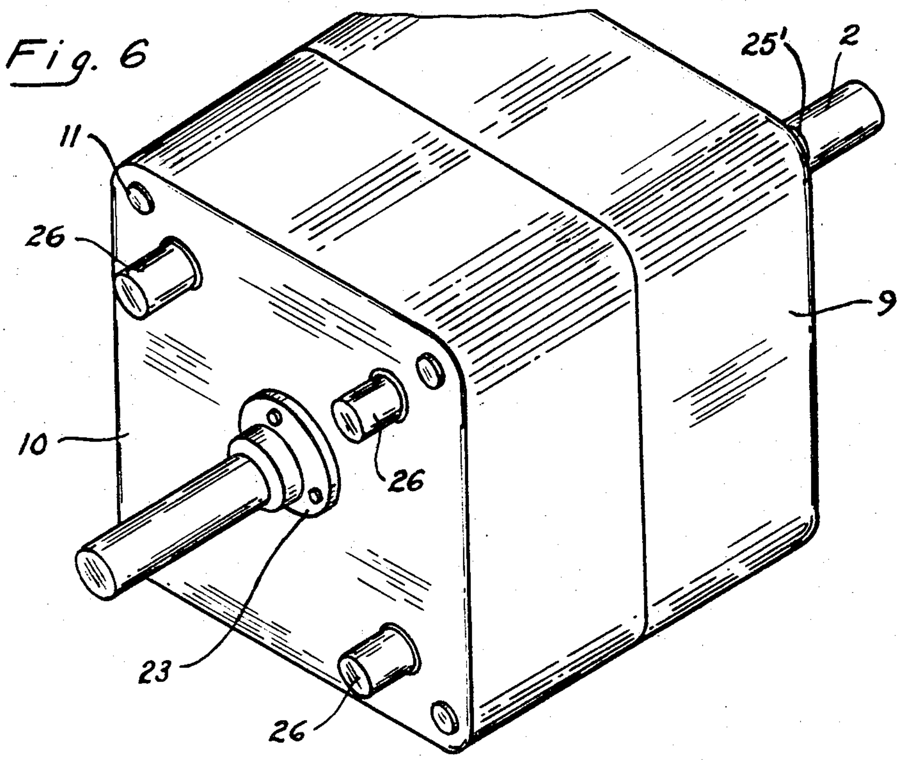
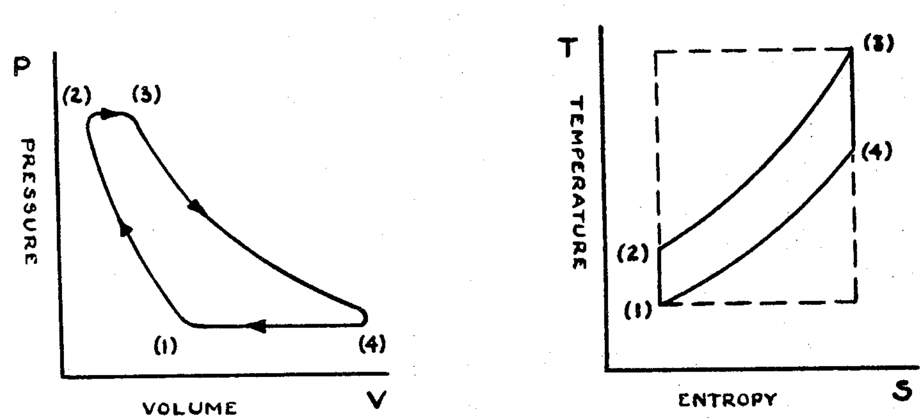


Fig. 7



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STIRLING CYCLE ENGINE WITH WAVE-CAM MEANS INTERCONNECTING PISTONS AND DRIVE SHAFT THEREOF

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ABSTRACT OF THE DISCLOSURE

A Stirling cycle engine having a drive shaft and a plurality of pairs of power and displacer pistons arranged radially about said drive shaft, and a wave-cam coaxially mounted upon the drive shaft for rotation therewith, said wave-cam having a cam track slidably associated with said pistons, whereby the reciprocating movement of the pistons imparts rotational movement to the drive shaft.

Various types of Stirling cycle engines are known, such as the conventional dual-coaxial reciprocating engine now in use, side-by-side piston types and L types. The currently used dual-coaxial piston engine is pressurized and operates at good efficiencies but due to its configuration is hampered by an excessive number of rods and linkages. This complex linkage system is a drawback to the simple ganging of the cylinder banks to achieve efficient, high power-to-volume Stirling engines.

The present novel design attempts to circumvent some of these deficiencies of the current engine by the application of a wave-cam on the drive shaft. This cam drive arrangement allows the classic dual side-by-side Stirling cylinders to be efficiently housed within a minimum volume unit. This cam drive advance permits utilization of a minimum number of working parts inasmuch as the pistons are directly connected to the cam track to thereby eliminate connecting rods, links and pins and the consequent wear of these parts. The present cam is of twin wave configuration thereby providing for a complete excursion of each piston within a 180 degree, ½ revolution of the drive shaft. In this arrangement, the required half-stroke phasing between the pairs of Stirling pistons is provided by placing the piston pairs at 45 degrees on the cam track. Since the twin wave-cam has been determined highly effective in view of its optimum displacement angle, the complete number of cylinders comprises four pairs or eight.

The aforementioned cylinders are considered in pairs since the displacer cylinder is the gas pressure generator for the power cylinder, which means that for the two-wave-cam there are four effective power cylinders.

The number of power cylinders may be increased by adding another cam in tandem with its cylinder bank, such arrangement being advantageous to the end of minimizing shaft and bearing problems. The two cams should preferably be 22 degrees out of phase to provide a maximum number of power pulses for smooth rotation with a minimum of vibration.

It will, therefore, be understood that the functions of the side-by-side Stirling pistons prevail in the present cam arrangement, with the necessary phasing between pistons being provided by their relative position on the cam track of the instant wave-cam.

Since the stroke of the multiple pairs of pistons are the same in view of the fixed cam throws, the bore of the displacer piston may be varied to obtain the optimum volumetric ratio.

The classic Stirling closed cycle is basically an externally heated engine in which a constant volume of gas

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is alternately heated and cooled to produce the half-power stroke and half-pull stroke on the power piston.

More specifically, the conventional Stirling engine consists of dual coaxial pistons, one displacer and one power piston reciprocating within a common cylinder. The approximately 90 degree phase angle at the crank-disc keys the cycle so that the displacer piston follows the power piston downward for the half-power stroke, thereby allowing the expanding gases to push effectively on the power piston. The two pistons are in-line and connected in phase to a common crank-disc and shaft. In the present arrangement, the displacer piston follows the power piston on the upward half-pull stroke.

Accordingly, and in consonance with the foregoing, it is a general object of the present invention to provide a simplified Stirling cycle engine while retaining all the characteristic efficiency of the cycle.

Another object of the invention resides in the achievement of a multiple-piston Stirling engine in the form of a minimum volume module.

A further object of the invention is to provide a relatively simple Stirling cycle engine which efficiently conducts heat to the displacer bore and maintains low ambient temperatures at the cold volume thereof.

Another object of the invention is to achieve maximum operating efficiency in a Stirling engine through the adoption of new and improved thermal saturation means.

A further object of the present invention resides in the provision of a device of the foregoing character which will operate without fluid lubrication and at a minimum friction level.

Another general object of the instant invention is to provide a device of the described character which will be simple in structure, economical of manufacture, and highly effective in use.

Other objects and advantages of the instant multipiston cam Stirling engine will be set forth in part hereinafter and in part will be obvious herefrom, or may be learned by practice of the invention, the same being realized and attained by means of the structure defined and pointed out in the appended claims.

The accompanying drawings referred to herein and constituting a part hereof, illustrate the invention, and together with the description, serve to explain the principles of the invention.

FIGURE 1 is a front elevational cross-sectional view of the engine;

FIGURE 2 is a side elevational partial cross-sectional view of the engine;

FIGURE 3 is a diametrical partial cross-sectional view of the engine;

FIGURE 4 is a phasing diagram of the relative positions of the displacer and power pistons and the location of the heating and cooling sources relative to said pistons;

FIGURE 5 is an exploded perspective view illustrating the various parts of the engine;

FIGURE 6 is a perspective view of the piston housing;

FIGURE 7 is a graphic representation of the pressure-volume and temperature-entropy characteristics of the engine.

The present preferred embodiment of the invention as illustrated in the accompanying drawings will now be described, twin wave-cam **1**, an essential element thereof being clearly seen in FIGURE 5. As shown therein, said wave-cam comprises identical wave portions A and B and is attached to drive shaft **2** to thereby transform the reciprocating thrusts of the power pistons **3** into rotary motion, the latter of which is imparted to said drive shaft.

Said power pistons, generally designated herein by numeral **3** and individually as **P1**, **P2**, **P3**, and **P4**, slide within power bores **4** and thereby transmit motion to cam track **5** of wave-cam **1** through roller bearings **6**, pins **7** being provided to secure said bearings to the sides of the power pistons, respectively, as shown. Piston rings **38** are fitted into grooves **39** in the pistons **3**.

The drive shaft **2** revolves on and is supported by thrust roller bearings **8** which are mounted in piston housing halves **9** and **10**, said housing halves being substantially identical, such halved arrangement permitting expedient assembly and disassembly of the engine. Said housing halves are mutually secured by tensile bolts **11** and nuts **12**, gasket **13** being provided therebetween for sealing purposes.

The displacer pistons, generally designated by numeral **14** and individually as D1, D2, D3, and D4, are reciprocated by the cam track **5** through roller bearings **15**, pins **16** being provided to secure said bearings to yolk members **17**, said displacer pistons being slidably received within displacer bores **18** as shown.

Sealing plate **19**, attached to the displacer pistons, provides a seal between said plate and displacer slot **20**, the latter being integrally provided in said piston housing as shown. Since the expanding working gas, e.g., air, must not escape into the cam volume region **20'**, the seal plates are required to effectively seal each displacer slot **20** with minimum sliding friction.

Said displacer pistons are preferably fitted with ball bearings **21** which are rotatably journalled by pins **22** within recesses provided within the longitudinal sides of said pistons to thereby reduce piston side play and friction within the displacer cylinder, said displacer pistons having sufficient wall gap with respect to said bores **18** to thereby allow the working gas to be shuttled back and forth within the displacer bores.

End flanges **23** position and support pressure seals **24** at each end of the housing and are secured to each housing half by screws **25**. Liquid sealant is preferably used to seal the joint between the end flanges and the housing halves.

Heat cylinders **26**, formed of copper or other suitable heat conductive material, conduct heat from an external heat source, e.g., a flame jet or other suitable heat source, to one end of each displacer bore **18**, said heat cylinders being insulated from the housing halves by dint of insulation liners **27**, said liners further providing a pressure-tight seal and allowing for the expansion of the heat cylinders. Cooling cylinders **25'**, also formed of copper or other suitable heat exchange material, extend as shown, contiguously with respect to cooling bore volumes **28'** to thereby cool said volumes by simple heat exchanges between said bores and the cooler temperature ambient said piston housing.

Two thrust collars **28** are secured to the drive shaft **2** at each end thereof and contact the inner race of the thrust roller bearings **8** to transmit thrust and to remove end play in the drive shaft.

Regenerator bores **29** and regenerator filaments **30** are located approximately midway in transfer ducts or conduits **31**, said ducts being provided to connect each displacer bore **18** with an adjacent power bore **4**, such connections being indicated in FIGURE 4 of the drawings. It is necessary to connect the midpoints of the displacer bores with the top sides of the power bores **4** so that a proper thermal balance is maintained within the displacer bore **18**.

As shown, ducts **31** are all sloped in the same direction in accordance with piston phasing requirements. The said regenerator filaments **30**, located within the regenerator bores **29** within the transfer ducts **31**, provide the means for storing the transmitted heat during one half-cycle and giving it up on the reverse flow for preheating of gas for the next heating half-cycle.

With reference now to FIGURE 3, fine saturation filaments **32**, as shown, are uniformly dispersed within the hot and cold ends of displacer bores **18**, said filaments being formed of beryllium-copper or other suitable heat conductive material. Those filaments disposed adjacently of said heat and cooling cylinders, are, as shown, connected thereto at **26'**, said filaments being effective in uniformly heating and cooling bore volumes **27'** and **28'**, respectively, and being adapted to flex on contact with the reciprocating displacer pistons.

Inasmuch as each pair of adjacent bores containing respective pairs of power and displacer pistons P1, D1; P2, D2; and P3, D3; and P4, D4 coact independently of the other pairs of adjacent bores, each of said pairs of bores is preferably fitted with gas filler valves **33**, a pressure gauge **34**, a safety plug **35** and a temperature gauge **36**, as shown, thereby allowing the user to regulate and observe the operating characteristics of each pair of respective bores. Two filler valves **33** are provided, one at each end of the power bores **4**, since the power piston seals off volumes **36'** and **37'** located, respectively, at opposite ends of said bores. In operation, the under ring volumes act as the bounce chamber during the cooled gas contraction and provide the thrust for an approximate half-stroke.

The pressure gauges **34** are preferably located at the power bore since such location will be at substantially mean temperature and working pressure, although subject to the high and low cycling surges. The temperature gauges **36**, as shown, are preferably arranged in proximity with respect to heat cylinders **26**, to thereby monitor heat flowing to each bore.

As a summary, then, the operation of the present invention is as follows: Each cylinder consists of two bores, placed side by side, with an interconnecting channel between them, and with a power piston in one bore and a displacer piston in the other (see FIG. 1). In order to transfer motion from the pistons to a rotatable shaft a wave cam is utilized, with the pistons riding on the cam face, and the various bores, and therefore the pistons themselves, being equally spaced around the periphery of the cam. The displacer piston is a loose fit within its bore to let air flow around it. The power piston is a tight fit within its bore and is timed to move slightly behind the displacer piston. As the power piston is pushed in (on starting or by flywheel momentum), it forces air through the channel connecting the bores, and compresses this air in the cold end of the displacer bore.

When the power piston is at the top of its stroke, the displacer piston has moved halfway down its bore and has transferred some of the cold air around its loose fit, up to the hot end of the bore. The compressed air expands as it is heated and drives the power piston out, while still more air is transferred as the displacer moves further down.

As the displacer moves up again it transfers air back to the cool space to be recompressed. Because of slight air loss, the cooled air is below atmospheric pressure, which therefore tends to suck the power piston in for another power stroke.

Although the preferred embodiment of the Stirling cycle engine structure has been described, it will be understood that within the purview of this invention various changes may be made in the forms, details, proportion and arrangement of parts, the combination thereof and mode of operation, which generally stated consists in a device capable of carrying out the objects set forth, as disclosed and defined in the appended claims.

What is claimed is:

1. In a reciprocating Stirling cycle engine which has no valves or spark plugs and which operates on the heating and cooling of the same air and having multiple pistons and a pressurized gaseous medium, the combination comprising a piston housing, a drive shaft rotatably mounted within said housing, wave-cam means mounted on said drive shaft for rotation therewith, a plurality of elongate bores within said housing, said bores each having a longitudinal axis and a forward and a rearward end and being radially arranged with respect to said wave-cam means, said longitudinal axes and said drive shaft being arranged in parallelism, multiple groups of coacting pairs of power and displacer pistons, roller bearings integral with each power and displacer piston for rolling contact with the wave cam, each of said pairs of pistons being slidably received within respective pairs of adjacently disposed bores for alternating phase reciprocation therewithin, passage means disposed between opposite ends of said displacer pistons and communicating with the top of said pistons.

2. The combination set forth in claim 1 including bearing means interposed between one of the pistons of said coacting pairs of pistons and the bore in which said piston is received.

3. The combination set forth in claim 2 wherein said one of the pistons is provided with a flat sealing plate connected to one side thereof and being received within a groove in the housing to prevent loss of the pressurized gaseous medium, and yoke means secured to said sealing plate for supporting the roller bearings.

4. The combination set forth in claim 1 including a relatively thin, flexible thermal conductive filament disposed at at least one end of said displacer piston bores.

5. The combination set forth in claim 1 including thermal regeneration means disposed within the said passage means of the piston housing.

6. The combination set forth in claim 1 including heat conducting means arranged proximately with respect to an end of each of said displacer bores, and a thermal saturation filament interposed between each of said heat conducting means and a relative displacer piston.

7. The combination set forth in claim 1 wherein said wave-cam means is of circular configuration and includes a cam track disposed peripherally thereof, said cam track including a pair of identical wave portions, said wave portions being 180 degrees apart.

References Cited

UNITED STATES PATENTS

1,006,269	10/1911	Philfer.	
1,229,009	6/1917	Allison.	
1,828,353	10/1931	Bleser	123—58 X
2,272,925	2/1942	Smith.	
2,482,831	9/1949	Arden	123—145
2,712,483	7/1955	Ciaccia	92—178

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