Oct. 29, 1968 D. A. KELLY 3,407,593

RECIPROCATING STIRLING CYCLE ENGINE WITH DUAL WAVE CAM DRIVE

Filed April 10, 1967 5 Sheets-Sheet 1

FIG 1

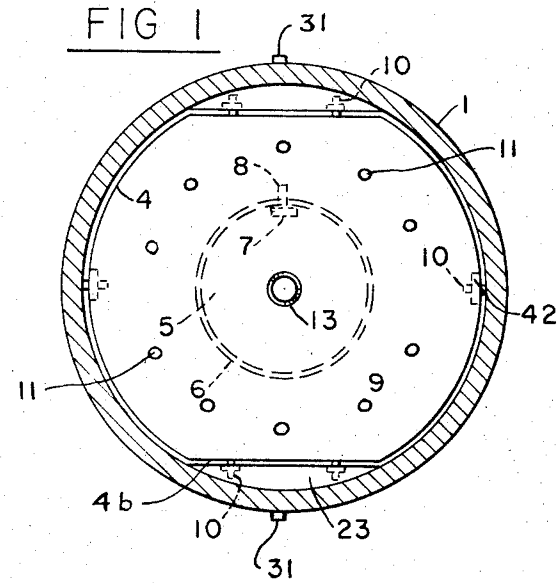
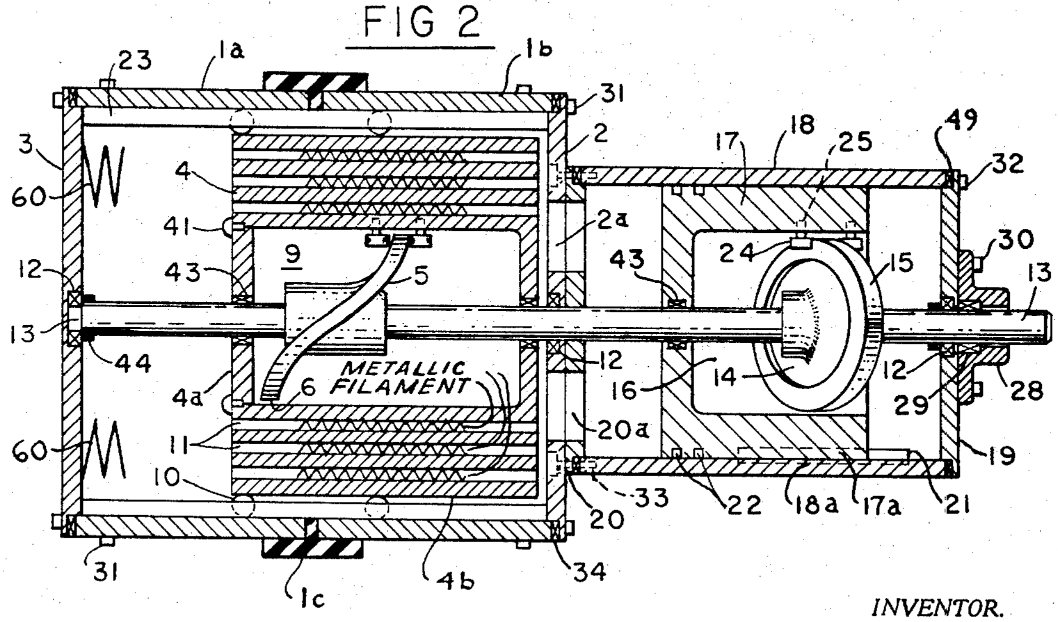


FIG 2



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Donald A Kelly

FIG 3

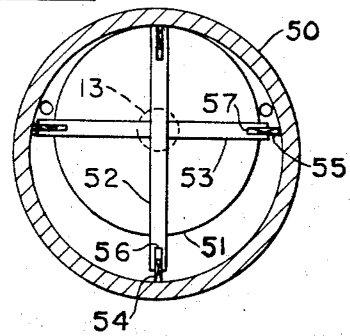
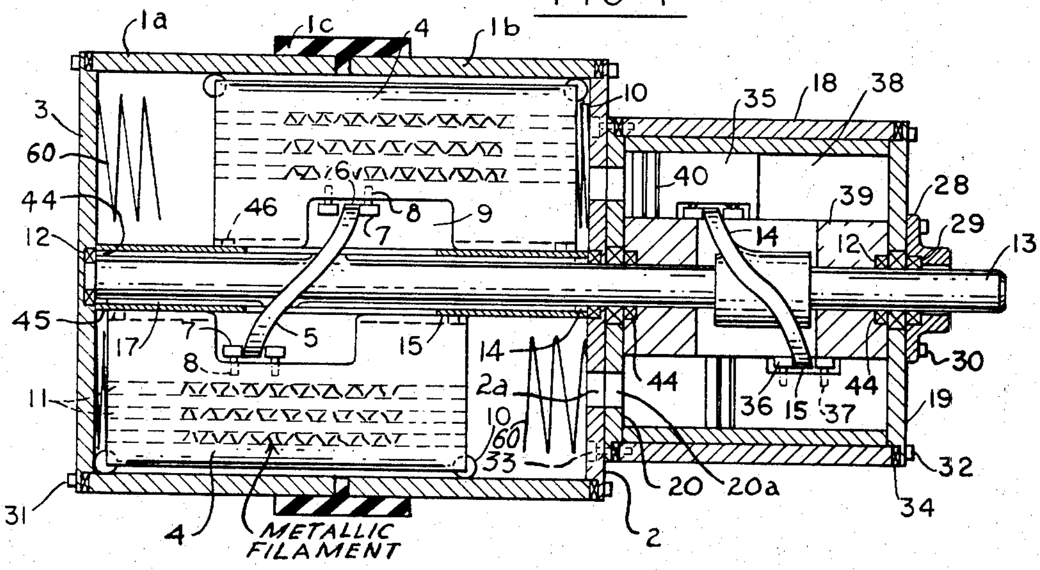


FIG 4



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Filed April 10, 1967 5 Sheets-Sheet 3

FIG 5

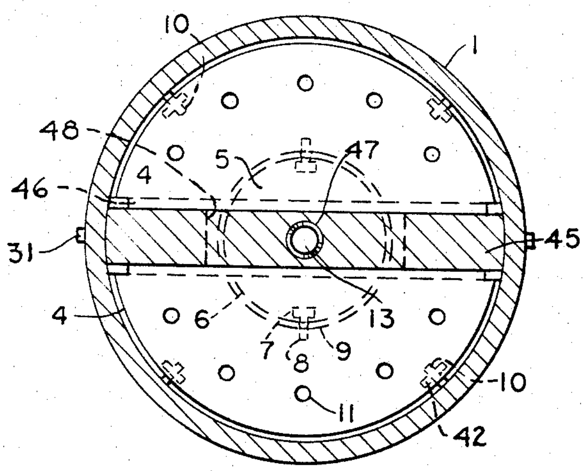
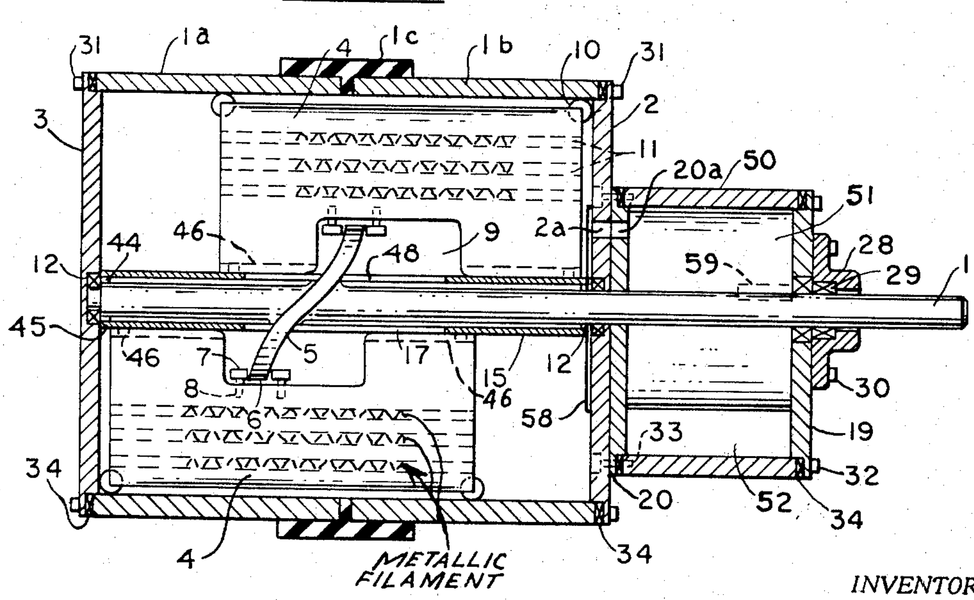


FIG 6



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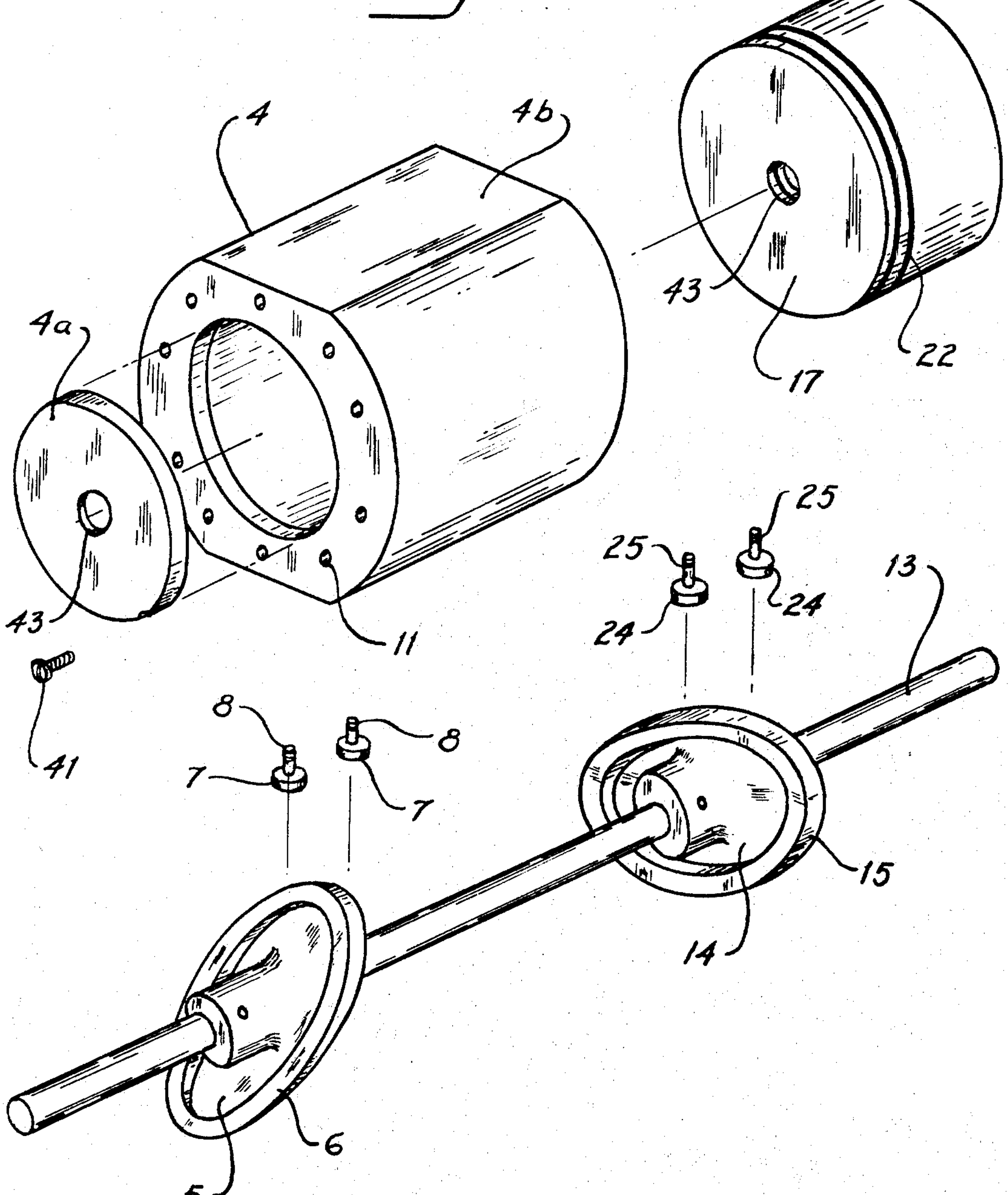
RECIPROCATING STIRLING CYCLE ENGINE WITH DUAL WAVE CAM DRIVE

Filed April 10, 1967 5 Sheets-Sheet 4

Fig. 7



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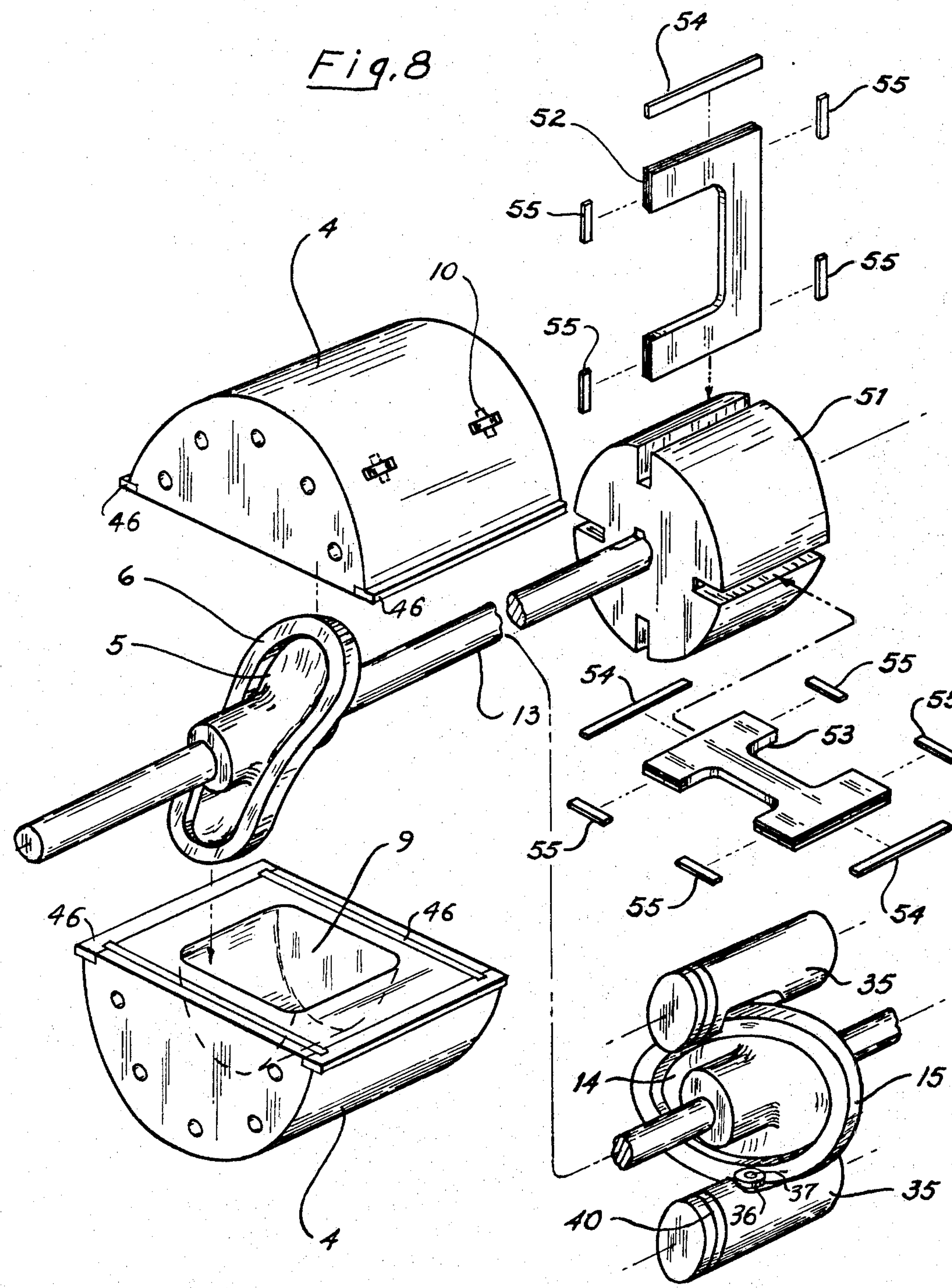
RECIPROCATING STIRLING CYCLE ENGINE WITH DUAL WAVE CAM DRIVE

Filed April 10, 1967

Fig. 8



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RECIPROCATING STIRLING CYCLE ENGINE WITH DUAL WAVE CAM DRIVE

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ABSTRACT OF THE DISCLOSURE

A Stirling cycle engine having two wave cams on a common shaft and two coaxial pistons connected to said wave cams which reciprocate within two cylinders; said wave cam having a cam track slidably associated with said pistons; said pistons being one-half stroke out of phase.

This invention relates to a simplified reciprocating Stirling cycle engine in which the two conventional pistons are coaxially arranged with two wave cams connected to them. The major difference between the conventional reciprocating designs and this arrangement is that wave cams are utilized to reciprocate with the pistons. The application of wave cams is viewed as a means of simplifying construction and producing a compact engine. The friction level at the cam track and rollers is minimized by the use of needle bearings revolving on the roller pins. In addition to reducing the number of parts such as rods and linkages and the wear associated with these, the application of wave cams affords a simple means of assembly and phasing adjustment between the Stirling piston pairs. Since a single wave cam is used the motion achieved is similar to a swash plate drive except that uniform motion results. Both wave cams have a helix angle of about 45 degrees for optimum rotation of the drive shaft without unduly high friction at the rollers. Unlike the twin-wave cam and multiple piston types previously disclosed the torque output is not doubled due to two power strokes per shaft revolution in this design. It should be noted that the single wave cam allows the pistons to fully traverse in one direction within the cylinders for 180 degrees of shaft rotation, which is identical to the operation of the conventional reciprocating Stirling cycle engine. When the cams are placed 90 degrees out of phase at the shaft, the two pistons are one-half stroke out of phase which is required for keying and proper operation of the cycle. Both pistons must be restrained from rotation in order to effectively translate within the cylinders and small roller bearings are provided within the cylinder to reduce rolling friction and guide the pistons.

The classic Stirling closed cycle engine is basically an externally heated engine in which a constant volume of gas is alternately heated and cooled to produce the half power stroke and half pull stroke on the power piston. 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 or V types. The currently operating 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 assembly is a drawback to the simple ganging of multiple cylinders to achieve efficient, high power-to-volume/weight Stirling engines.

The present unique design allows the classic Stirling cycle pistons to be simply phase connected in a readily serviced compact arrangement. The design circumvents the complex linkage required by the current co-axial engine, by the application of the two wave cams on a common drive shaft. It should be realized that the displacer piston receives energy for reciprocation from its wave cam, while the power piston transmits thrust to its wave cam to produce the torque at the common drive shaft, and this functioning is similar to the compressor and power stages of a standard open cycle gas turbine. In this arrangement the displacer piston strokes need not be the same as that of the power piston since each piston has its own wave cam and therefore each displacement stroke may be suited to the volumetric arrangement required.

In this engine design no special attempt is made to approcah true isothermal operation by the addition of interlocking fins or saturation filament at both ends of the displacer cylinder, although such methods may be employed if the specific engine application dictates that operating efficiency would be enhanced. The acceptance of the expansion and compression function closer to adiabatic than isothermal is viewed as characteristic of general Stirling cycle configuration and it would appear that improved efficiencies will result by improved regeneration techniques and volumetric proportions.

A means of aiding thermal operating efficiency in this design is the splitting of the displacer housing and the isolation of the two halves into hot and cold sections to achieve a maximum delta temperature. The heating of the hot section would be accomplished by direct flame on the cylinder wall or through a conductive metal volume which would serve to store heat. The cooling of the cold section would be accomplished by placing continuous liquid cooling tubes in direct contact with the cylinder walls or possibly embedded within the walls of the cold section. This arrangement, although not as theoretically efficient as other systems is within the realm of producibility and economical feasibility.

This cycle can be inverted to operate as refrigeration equipment when coupled to a suitable power source such as an electric motor. When the machine is operated in this manner the normally hot side will become cold and the normally cold side will become hot. A distribution and heat sink arrangement must be made to utilize the cooling produced.

An alternate arrangement of the basic engine would consist of a relatively large twin semi-circular displacer piston halves and a single wave cam as a displacer section with small twin pistons and single wave cam, as a power section. The single wave displacer cam would reciprocate the displacer piston halves in opposite directions within the displacer cylinder to form the standard hot and cold displacer volumes. The displacer piston halves contain cavities sufficient to allow for the clear revolution of the cam within the piston halves. The piston halves are restrained from tending to revolve with the rotating cams by the divider plate. The divider plate separates the two displacer piston halves and seals off the two displacer cavity halves. Since the semi-cricular displacer piston halves are located at opposite ends of the single wave cam and therefore move in opposite directions, their thrusts cancel out so that running roughness and vibrations are minimized. The twin displacer halves would be fitted with ball bearings to suspend the pistons from contact with the displacer cylinder walls.

The twin power pistons drive the power cam which is 90 degrees out of phase with the displacer cam. Four power pistons may be utilized to provide double the power pulses on the cam track for more uniform power flow. The expanding and contracting gas flow would be conducted through multiple ports between the displacer and power sections.

It is most desirable to simplify Stirling engine design in order to simplify manufacture, operation, servicing and maintaining, while achieving a maximum power-to-volume output.

It is an object of the invention to create a simple Stirling cycle engine while maintaining all the operating characteristics of the cycle.

It is a further object of the invention to create a simplified Stirling cycle engine with independent strokes for each piston and ease of phase adjustment by utilizing two wave cams on a common drive shaft.

It is an object of the invention to create a long-lived, maintenance-eased Stirling engine without the requirement of a high pressure seal at the output shaft.

It is an object of the invention to simplify regeneration techniques by adopting multiple, long-path, small diameter regenerator bores within the displacer piston or pistons.

It is a final object of the invention to produce a low-cost engine or refrigeration machine that is easy to assemble, disassemble and service,

Other features will become apparent from the following description of the engine design. It should be understood that variations may be made in the detail design without departing from the spirit and scope of the invention.

Referring to the drawings in detail,

FIGURE 1 is a front section view through the displacer cylinder section.

FIGURE 2 is a side section view through the engine.

FIGURE 3 is a front section view through an alternate rotary power section.

FIGURE 4 is a side section view through an alternate engine arrangement.

FIGURE 5 is a front section view through an alternate displacer section.

FIGURE 6 is a side section view through an alternate half-rotary engine.

FIGURE 7 is a pictorial exploded view of the preferred engine operating components.

FIGURE 8 is a pictorial exploded view of the alternate engine operating components.

Referring to FIGURE 1 and 2, the displacer cylinder **1** is made up of three parts, a hot cylinder **1***a*, a cold cylinder **1***b*, and an insulation sleeve **1***c*, which form an integral, inseparable displacer cylinder.

The end plates **2** and **3** are secured to the displacer cylinder **1** to form a sealed displacer housing. The screws **31** fasten the end plates **2** and **3** to the displacer cylinder **1** with the gasket **34** making the displacer housing gastight. The cylindrical displacer piston **4** reciprocates within the housing and is suspended with small clearance from the inside diameter by the ball bearings **10** and pins **42**. The sealing disc **4***a* provides a means of assembly and seals the displacer gas volume from entering the displacer cavity **9**. The screws **41** secure the sealing disc to the cavity diameter with suitable sealing compound providing a gastight pressure seal. The two guide segments **23** are fastened to the inside diameter of the displacer housing by the screws **31**. The guide segments **23** prevent the displacer piston from revolving by coacting with the displacer flat **4***b* and the ball bearings **10**.

The displacer wave cam **5** is secured to the drive shaft **13** with the cam track **6** forming the displacement means for the roller bearings **7** and pins **8**. The rollers and pins are secured to the inside diameter wall of the cavity **9** which provides displacement clearance for the piston about the wave cam **5**, during its excursions. Small diameter regenerator bores **11** are located equally spaced around the end surface of the displacer piston **4** and run through it parallel to the drive shaft axis.

The roller bearings **12** support the drive shaft **13** within the end plates **2** and **3**.

The power wave cam **14** is secured to the drive shaft **13** with the cam track **15** forming the displacement means for the roller bearing **24** and pin **25**. The roller and pin are secured to the inside diameter wall of the power piston cavity **16**. The cavity **16** is the open portion of the power piston **17** in which the power cam **14** rotates and which provides displacement clearance for the piston during its power excursions.

The power cylinder **18** to which the end plates **19** and **20** are fastened form the sealed power cylinder housing with the gasket **49** making the power cylinder housing gastight. The screws **32** and **33** fasten the end plates **19** and **20** to the power cylinder **18**. The long rectangular key **21** is secured to a slot **18***a* within the inside wall of the power cylinder and fits in a corresponding slot **17***a* within the power piston **17**, which prevents the power piston from revolving.

The power piston rings **22** are fitted to the piston to seal the gas within the working volume.

The front flange **28** contains the shaft seal **29** in contact with the shaft **13** and the front plate **19**. The screws **30** secure the flange **28** to the front plate **19**. The sealing rings **43** are required to prevent the working gas from escaping by the pistons **4** and **17** at the shaft **13**. These rings will be subjected to severe conditions since they must seal against both rotation and reciprocation at the shaft, and will likely be made of Viton. The shaft **13** will require a finish of 16V− or better to prevent undue wear on the seals.

The thrust collars **44** secured to the drive shaft **13** and transmit the axial piston thrust to the roller bearings **12**.

The multiple ports **20***a* in end plate **20** and **23***a* in end plate **2** must be equal in size and line up in order to transmit the ebb and flow of the internal working gas, acting on the power piston **17**.

In the alternate arrangement the same displacer cylinder **1** and housing components will be required as in the first design. A divider plate **45** will split the displacer housing longitudinally at the horizontal centerline and be secured to the inside cylinder walls with the screws **31**. The bore **47**, at the exact longitudinal center of the divider plate provides clearance for the drive shaft **13**. An opening **48** in the center of the divider plate **45**, provides clearance for the rotation of the displacer wave cam **5**.

The displacer pistons **4** are identical halves and slide in contact with the two faces of the divider plate **45**. The displacer wave cam **5** is secured to the drive shaft **13** with the cam track **6** forming the displacement means for the roller bearings **7** and pins **8**. The roller bearings and pins are secured to the inside diameter wall of the piston cavity **9**.

Since the piston halves **4** are connected to diametrically opposite ends of the displacer wave cam **5** their displacement is equal and opposite to each other. The piston halves are restrained from a tendency to rotate by their contact with the divider plate **45**. The contact with the divider plate is maintained by the bearings **10** and pins **42** located on the periphery of the displacer halves, while also providing the small clearance necessary between the piston halves and the inside diameter of the displacer housing.

The seals **46** located across the ends and sides of the "flats" of the displacer halves serve to seal the working gas from entering the displacer cavity **9**. Small diameter regenerator bores **11** are located equally spaced around the end surface of the displacer piston **4** and run through it parallel to the drive shaft axis. The roller bearings **12** support the drive shaft **13** within the end plates **2** and **3**.

The thrust collars **44** secured to the drive shaft **13** and transmit the axial piston thrusts to the roller bearings **12**.

The power section consists of the same components as in the first design, **18**, **19**, **20**, **32** and **33** into which a cylindrical piston block **39** is retained. Two, four or more piston bores **38** contain the multiple power pistons **35**. The power wave cam **14** is secured to the drive shaft **13** with the cam track **15** forming the thrust transmitting means from the roller bearings **36**. The power cam **14** is placed about 90 degrees out of phase with the displacer cam **5** as required to key the cycle. The rollers and pins **36** and **37** are secured to the power pistons, which reciprocate within the power bores **38**.

Additional thrust collars **44** secured to the drive shaft **13** transmit the axial piston thrusts to the bearings **12**. The two bearings **12** are located within the end plates **19** and **20**.

The end flange arrangement **28** is the same as the first design and includes parts **29**, **30**.

It may be possible to eliminate power cylinder components **18**, **19**, and **20**, if the cylindrical piston block **39** is of sufficient strength to contain the high internal pressures developed within the power section.

The multiple ports **20a** in the end plate **20** and **2a** in the end plate **2**, must be equal in size and line up with the power piston bores in order to transmit the ebb and flow of the internal working gas, acting on the power pistons **35**. The piston rings **40** seal the working gas from escaping and assure power transmission to the power cam. As is evident the number of transmitting ports **20a** and **2a** sets will be equal to the number of power pistons.

An alternate power section would consist of a rotor and sliding vane assembly eccentrically rotating in a cylindrical housing **50**. The slotted rotor **51** would contain the shaped vanes **52** and **53** which interlock and slide to maintain contact and seal the crescent cavities within the rotary power section, housing **50**. The vanes would be sealed gas pressure tight by the seals **54** and **55**, which are held in contact with inside diameter walls by the springs **56** and **57**, respectively. A valve disc **58**, is fastened to the drive shaft within the power cylindrical to isolate the hot gas flow from the cold, during the cycle.

The multiple ports **20a** in the end plate **20** and **2a** in the end plate **2** line up with the power housing cavities and with the ports of the valve disc **58**. A key **59** secures the rotor **51** to the drive shaft **13**. The end flange arrangement **28**, **29**, **30** is the same as in the first design.

Various gauges will be required for the engine, but these are not shown nor described in detail since they are incidental to the overall engine designs. Gas filler valves will also be required and these are not shown since they may be placed at any convenient point in the engine housing.

An additional shaft extension may be required for driving an alternator and an electric starter drive. An electric starter system would be required, with an alternator recharging the battey through a voltage regulator. The battery would supply the current required by the starter as in a conventional system. No other accessories would be required with the possible exception of a liquid fuel pump.

An optional component for all the engine designs would be the addition of thin, flexible metallic strips **60**, which serve to conduct heat uniformly throughout the heated displacement volume. For convenience in assembly the strips would be attached to the end plate **3**.

What is claimed is:

1. In a reciprocating Stirling cycle engine having two coaxial pistons and a pressurized gaseous medium; the combination comprising two coaxial piston housings; a drive shaft rotatably mounted within said housing; two wave cam means mounted on said drive shaft for rotation therewith; guidance and bearing means within said two coaxial pistons for rolling association with said wave cam

means; keying means within each of said piston housings for coaction with said two coaxial pistons; bearing means for said drive shaft rotatably mounted within said housing; sealing means within said two coaxial pistons for slidable association with said driveshaft.

2. The combination set forth in claim **1** including a sealing disc bonded to one end of one of said coaxial pistons.

3. The combination set forth in claim **1** including multiple small diameter regenerator bores axially disposed within one of said coaxial pistons; fine metallic filament dispersed within said multiple small diameter regenerator bores.

4. The combination set forth in claim **1** wherein one of said two coaxial pistons is provided with axially disposed bearing means.

5. The combination set forth in claim **1** including thin flexible metallic strips uniformly disposed at both ends of one of said two coaxial piston housings.

6. In a receprocating Stirling cycle engine having two semicircular piston halves; multiple small diameter pistons and a pressurized gaseous medium; the combination comprising two coaxial piston housings; a longitudinal divider plate within one of said two coaxial piston housings thereby forming two semi-circular elongate cavities within said piston housing; said longitudinal divider plate and said drive shaft being arranged in parallelism; a drive shaft rotatably mounted within said two coaxial piston housings; two wave cam means mounted on said driveshaft for rotation therewith; guidance and bearing means within said two semi-circular piston halves for rolling association with one of said wave cam means; guidance and bearing means on said multiple small pistons for rolling association with the other said wave cam means; bearing means for said drive shaft within said two coaxial piston housings; sealing means within said piston halves for slidable association with said longitudinal divider plate and one of said coaxial piston housing and the bores therein.

7. The combination set forth in claim **6** including multiple small diameter regenerator bores axial disposed within said two semi-circular piston halves.

8. The combination set forth in claim **6** wherein the said two semi-circular piston halves are fitted with axial disposed ball bearing means.

9. The combination set forth in claim **6** including thin flexible metallic strips uniformly disposed at either or both ends of said two coaxial piston housings.

10. In a reciprocating Stirling cycle engine having two semi-circular piston halves and a pressurized gaseous medium, the combination comprising a displacer housing; a drive shaft rotatably mounted within said displacer housing; a wave cam means mounted on said drive shaft for rotation therewith; a longitudinal divider plate within said displacer housing thereby forming two semi-circular elongate cavities; said longitudinal divider plate and said drive shaft being arranged in parallelism; guidance and bearing means within said two semi-circular piston halves for rolling association with said wave cam means; bearing means for said drive shaft within said displacer housing; sealing means within said two semi-circular piston halves for slidable association with said longitudinal divider plate; two ports disposed at one end of said displacer housing; a second cylindrical housing disposed coaxially with said displacer housing; a slotted rotor eccentrically located within said second cylindrical housing; a short bore in said slotted rotor; multiple movable and interlocking power vanes disposed within said slotted rotor; sealing means within said power vanes for slidable association within said cylindrical housing which line up with said two ports at one end of said displacer housing.

11. The combination set forth in claim **10** including multiple small diameter regenerator bores axially disposed within the said two semi-circular piston halves; fine metallic filament dispersed within said regenerator bores.

12. The combination set forth in claim **10** wherein the said multiple movable and interlocking power vanes are in independent of each other; spring loading means for said independent power vanes.

13. The combination set forth in claim **10** including a valve disc secured to the said drive shaft within the said displacer housing.

14. The combination set forth in claim **10** wherein said second cylindrical housing is fitted with a seal means in rotating association with said drive shaft.

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