Feb. 3, 1970 D. A. KELLY 3,492,818

ROTARY STIRLING ENGINE-WITH SLIDING DISPLACER ROTOR

Filed July 1, 1968 3 Sheets-Sheet 1

FIG. 1

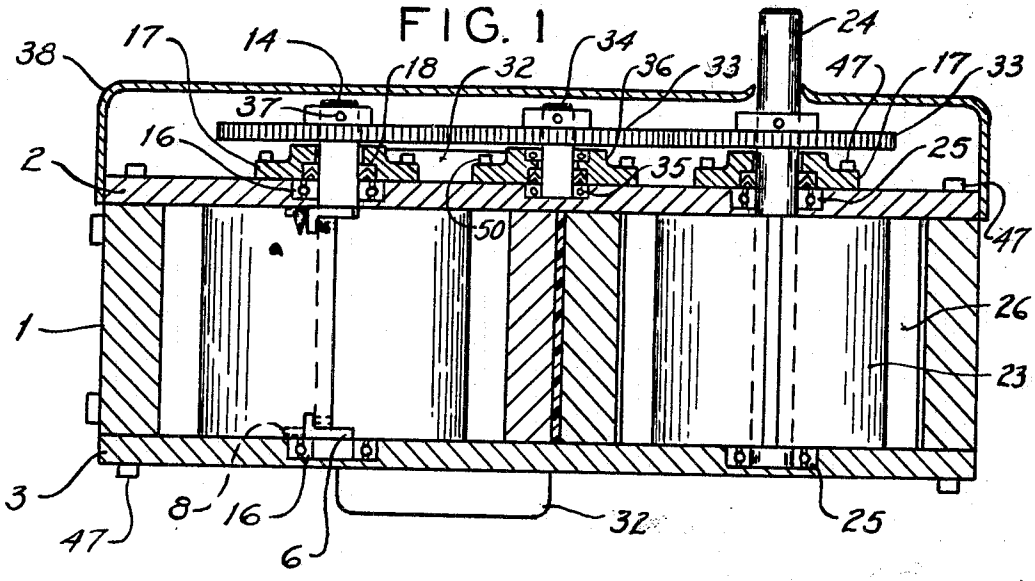
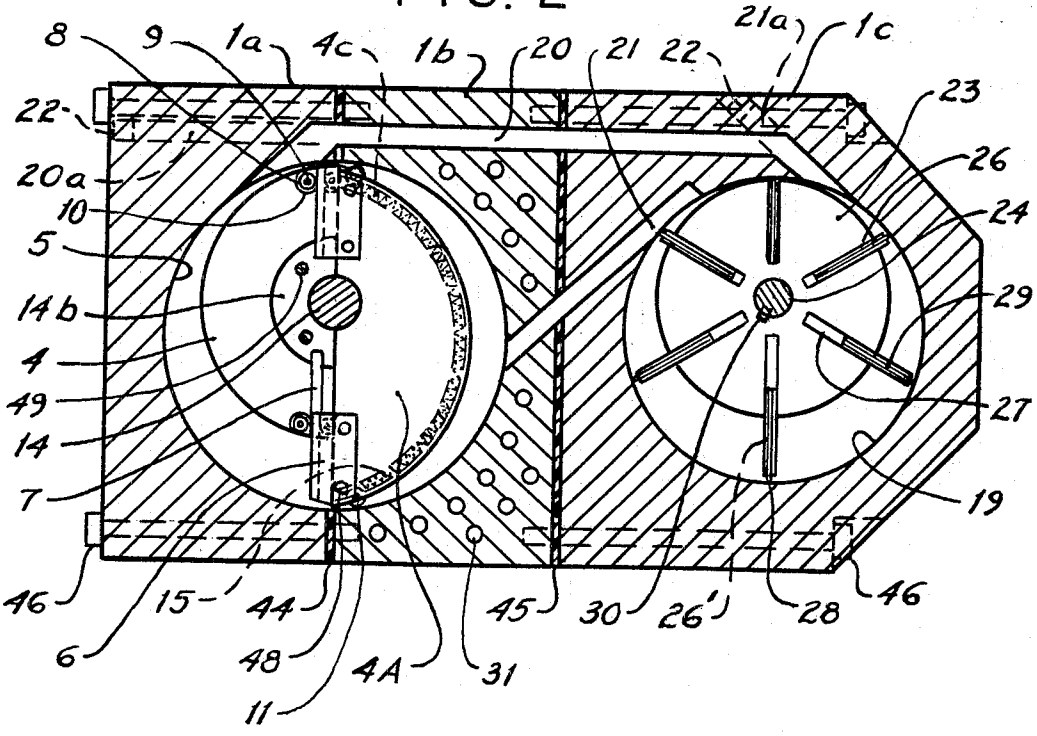


FIG. 2



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ROTARY STIRLING ENGINE-WITH SLIDING DISPLACER ROTOR

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FIG. 3

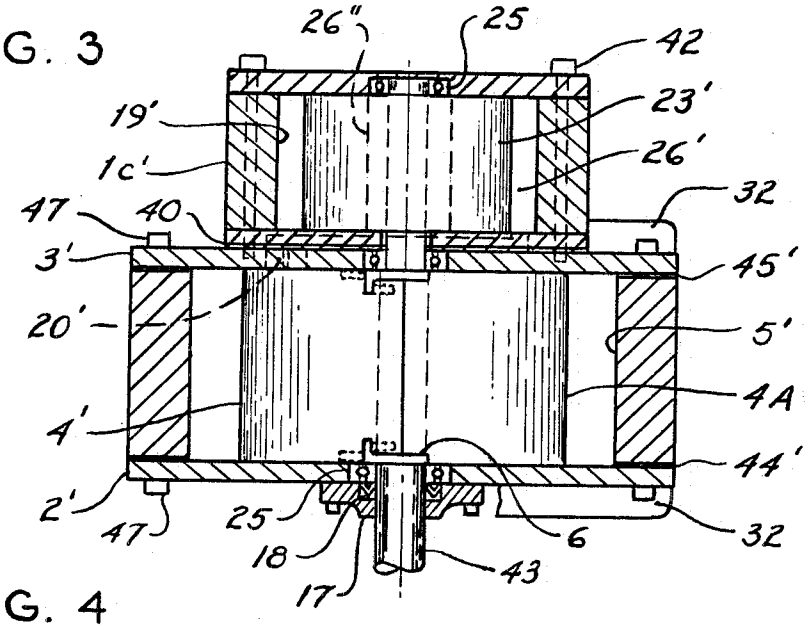
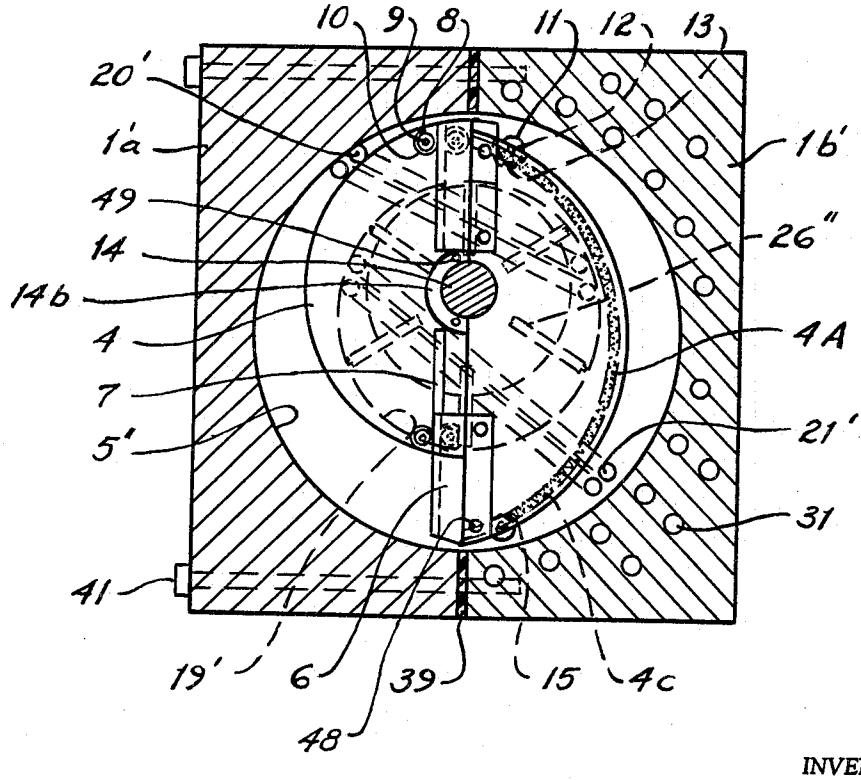


FIG. 4



INVENTOR.

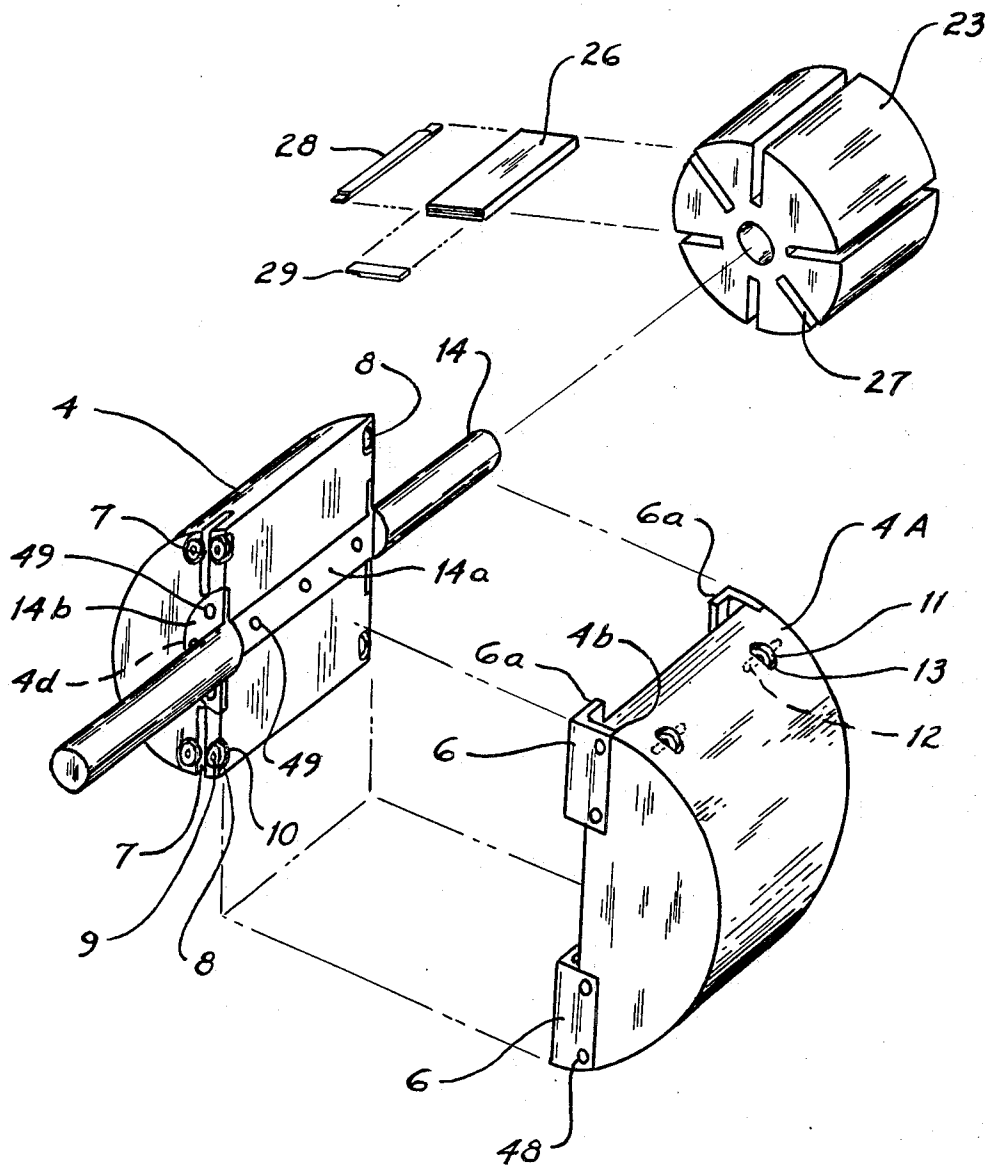
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ROTARY STIRLING ENGINE-WITH SLIDING DISPLACER ROTOR

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FIG. 5



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3,492,818

ROTARY STIRLING ENGINE—WITH SLIDING DISPLACER ROTOR

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U.S. Cl. 60—24 10 Claims

ABSTRACT OF THE DISCLOSURE

The rotary Stirling cycle engine comprises a modified displacer stage and a multiple sealed vane power stage suitably coupled to form a compact modular power package.

The engine arrangement is similar to prior rotary Stirling engine art except that the characteristics of the reciprocation type engine are more closely duplicated with the advantage of fewer and simpler rotary components. The regeneration ducts in the semi-circular displacer produce efficient thermal regeneration within the displacer stage.

This invention relates to a modified rotary Stirling cycle engine including both axial and radial gas flow versions. This modified rotary engine is a combination of the features of the prior Patent No. 3,370,418 and the Rotary Stirling engine Ser. No. 723,721, filed Apr. 24, 1968. The displacer design features of these engines are combined to more closely duplicate the operating characteristics of the classic reciprocating types of Stirling cycle engines and the known high efficiency of this art.

Specifically the near semi-circular displacer of the prior reference and the eccentric displacer rotor of the latter reference are combined to produce the necessary transfer pressure of the heated gas within the displacer stage. The heated gas, in an isothermic expansion process, is thereby effectively transferred to the power stage to act on the vanes of the power rotor.

The present engine modifications overcome the deficiencies of the prior reference in this respect and further eliminate the necessity of the vane sealing of the latter reference. In the displacer vane type of rotary engine sealing is necessary between the two separate hot and cold volumes of the displacer stage with attendant friction and lubrication problems being introduced.

The displacer vane type of displacer element also represents a compromise in the internal regeneration requirements in that the paths or ducts must be folded to produce the required full semi-circular regeneration path.

When the two displacer features in the references are combined it is seen that the semi-circular displacer member must reciprocate or slide on the smaller base half-rotor during rotation due to the eccentricity of the displacer shaft within the displacer bore. The semi-circular displacer member would contain anti-friction rollers which would contact the displacer bore and guide the member during its rotation. Guide angles would be secured to the displacer member which would fit into corresponding slots in the base half-rotor. Ball bearings would be recessed into the faces of the base half-rotor to contact and closely guide the legs of the guide angle so that the displacer member slides at a constant distance from the rotor center.

The displacer member would be dynamically balanced and as lightweight as possible to keep the vibration frequency to a minimum. Vibration must be kept low so that bearing, seal and other component life is not unduly shortened.

The displacer member revolves at a close clearance within the displacer bore so that a minimum of internal gas volume is not working.

The multiple regenerator ducts are uniformly spaced along the width of the displacer and at the greatest possible radius to provide a minimum of cutoff arc as the top tangency position is reached.

The regenerator bores are fitted with regenerative filament to implement heat storage while minimizing gas flow resistance. In operation the filament would pick up heat as the displacer member sweeps into and through the hot section for 180 degrees and release it as the entering cool gas then pushes it through into the hot zone.

The power rotor would be fitted with about six or eight independently sealed vanes which should be lightly spring loaded. The independent vanes would have the advantage of not requiring the seals to be spring-loaded as in the interlocking type of power vanes. All other elements and design features of the engine would be the same as in the eccentric vane-displacer modular arrangement or latter reference, since this provides a simple and effective construction means.

This engine cycle consists of heating the fixed internal volume of gas which expands isothermally to perform work, and then cooling the gas which compresses isothermally to return to the original condition. Since the conventional reciprocating Stirling engine combines the cold clearance volume with the power piston volume, a certain amount of thermal loss occurs when the hot expanding gas contacts the cold wall area which results in a loss of efficiency. This deficiency would be overcome in these rotary Stirling engines since the hot and cold flow paths are isolated from each other.

In this rotary engine design, an eccentric base half rotor and displacer member takes the place of the displacer piston and the second eccentric rotor and multiple vanes function as the power piston, with the basic advantages of a rotary machine, including uni-inertia and fewer operating parts. Since the rotor operation is continuous there is no phasing requirement between the stages.

In the axial flow or tandem arrangement the alternately expanding and contracting gas is forced to enter and leave the respective bores of the power stage. The tandem arrangement has the advantage of providing a compact, and convenient engine in use with a minimum of interconnecting bores. In the radial flow arrangement the hot expanding gases are centrifugally directed by the rotating displacer member into the power stage where it rotates the power rotor and vanes. During the cooling half portion of the cycle the contracting gas flows into the displacer bore providing a pull effect on the power vanes.

In the radial flow design the heat source would be at the outside of the displacer bore, and the cooling tubes located between the two bores so that the engine will have only one direction of rotation. In the axial flow design, since the two stages are in-line the heat source and the cold source may be interchanged so that either direction of rotation may be obtained.

The displacer member must be reversed when the direction of rotation is reversed due to the "flat" orientation.

The adoption of modular design is advantageous since the hot and cold sections may be conveniently separated and insulated from each other.

In the radial flow design the engine block should be divided into three nearly equal volumes, one for the hot side, one for the cold side and the last one for the power stage. The three would be insulated from each other keyed and bolted to form the complete module.

The axial flow module would also consist of three sections, with two sections side-by-side and the remaining one centrally fixed behind the two. The hot and

cold sections would be on either side with the power section equally behind these and secured to both. The three would be keyed and insulated from each other to maintain the necessary thermal isolation.

The engine, as a closed cycle machine, must be provided with a high temperature dry film lubricant and antifriction seals, so that no internal circulating oil system will be necessary. Effective long-life dry lubrication is of great importance to the efficient operation of the engine.

It is an object of the invention to achieve a simple, efficient rotary Stirling engine with a minimum of expensive components.

It is an object of the invention to achieve a simple rotary Stirling engine by utilizing the advantages of true rotary elements.

It is an object of the invention to achieve maximum operating efficiency in a rotary engine by closely duplicating the cycle functioning of reciprocating Stirling engines.

It is an object of the invention to produce a rotary Stirling engine that is inexpensive and simple to manufacture.

It is an object of the invention to produce a rotary Stirling engine which operates on dry film lubrication.

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:

FIGURE 2 is a front section through the radial flow version of the engine.

FIGURE 2 is a front section through the radial flow version of the engine.

FIGURE 3 is a top section through the axial flow version of the engine.

FIGURE 4 is a front section through the axial flow version of the engine.

FIGURE 5 is a pictorial exploded view of the various displacer elements.

Referring to the drawing in detail:

The engine block 1 is divided into three sections which are nearly equal in volume. Section 1*a* is the hot section, 1*b* is the cold section and 1*c* is the power section. The sections are insulated from each other by the two gaskets 44 and 45 and secured together with the bolts 46. The front plate 2 and the rear plate 3 are secured to the engine block 1 by the screws 47.

The displacer base half-rotor 4 is offset within the displacer bore 5 and is set at near tangent contact at the upper end of the bore 5. The sliding displacer member 4A is semi-circular in shape having a diameter which is slightly less than the displacer bore 5 diameter. The displacer member 4A is provided with four guide angles 6, secured on the steps 4*b* with the screws 48. Corresponding slots 7 are located in the base half-rotor 4 into which the guidance legs 6*a* of the guide angles 6 fit with clearance. Ball bearings 8 and pins 9 are recessed into the bores 10 within the base half-rotor 4 to engage and guide the guidance legs 6*a* of the guide angle 6, and thereby allow the displacer member 4A to slide back and forth at a fixed distance from the center. The guide angles 6 are made long enough to retain the displacer member 4A in both extreme end positions, but must also clear the rotor shaft 14 in these extreme positions.

Ball bearings 11 and pins 12 are uniformly recessed into slots 13 within the periphery of the sliding displacer member 4A, so that the displacer member freely rolls around within the displacer bore 5, at a constant close clearance. Multiple circular regenerator bores 4*c* are uniformly located within the displacer member 4A, with fine regenerative filament 15 uniformly arranged within the bores 4*c*. The regenerator bores 4*c* are at a maximum radius to be most effective.

The rotor shaft 14 must be provided with a diametral notch 14*a* in order that the displacer member 4A may slide on the flat surface of the base half-rotor 4.

The rotor shaft 14 must also be provided with a torque half-flange 14*b*, which may be welded in place at the output end of the shaft. The rotor shaft 14 would be secured to the base half-rotor 4 with the screws 49 along the notch 14*a* and through the torque half-flange 14*b*. The torque half-flange 14*b* must be mounted flush into the recess 4*d* within one end of the base half-rotor 4.

The two rotor bearings 16 support the base half-rotor 4 and shaft 14 within the engine block 1 and plates 2 and 3.

The retaining flanges 17 carry the shaft seals 18 which pressure seal the shafts in the engine block 1. The retaining flanges 17 are secured to the rear plate 3 with the screws 47, with suitable sealant used to make a pressure tight seal between the retaining flanges 17 and the rear plate 3.

The power bore 19 is located in the engine block section 1*c* and is connected to the displacer bore 5 by the multiple hot transfer bores 20 and the multiple cold transfer bores 21. The entrance bore 20*a* and 21*a* are sealed with the threaded plugs 22. The hot and cold transfer bores 20 and 21 are offset from each other, so that the bores do not intersect and cause leakage.

In some arrangements the hot transfer bores 20 may be tapered to provide additional compression during the hot gas transfer. The larger diameter would be at the displacer end of the bores with the smaller diameter at the power bore.

The power rotor 23 closely fits at one point and revolves in the power bore 19 and is supported by the output shaft 24. The two rotor bearings 25 support the power rotor and the output shaft 24 within the engine block 1 and the plates 2 and 3. The multiple power vanes 26 are closely fitted into corresponding slots 27 within the power rotor 23, and have free radial movement in the slots 27. Low friction seals 28 and 29 are closely fitted into corresponding slots 26′ within the three sides of the power vanes 26. The sealing arrangement for each vane consists of one long rectangular seal 28 at the top and two short seals 29 at the sides for complete sealing. The ends of the adjacent seals are half-lapped so that they interlock to form a continuous sealing area. The power rotor 23 has a through bore into which the output shaft 24 is closely fitted. The power rotor 23 is keyed to the output shaft 24 with the key 30.

The engine block section 1*b* contains the multiple liquid coolant holes 31 axially arrayed around the periphery of the displacer bore 5. The coolant holes 31 must cover nearly 180 degrees of the displacer bore and must be approximately two dozen in number to assure sufficient cooling flow volume for the cold section.

Two manifolds 32 will be placed over all the cooling holes 31 at either side of the engine to distribute and collect the coolant as it is pumped through the system.

Three identical spur gears 33 are secured to the shafts 14, 24 and the idler shaft 34. This arrangement allows the two stages to rotate at the same speed and in the same direction so that the cycle may function properly.

The idler shaft 34 is supported by the two ball bearings 35 and flange 36. The flange 36 is secured to the rear plate 3 by the screws 50. The gears are locked on their respective shafts by the pins 37. A snap-on cover 38 encloses the gear assembly to provide dirt exclusion and protection of these components.

In the axial design, the engine block 1 contains the displacer bore 5′ at one end and the bore 19′ at the opposite end with both on the same center line. All the rotating elements of the radial flow engine version are the same as in the axial design since the functioning is identical. The hot section 1*a*′ is connected side-by-side to the cold section 1*b*′ with the power section 1*c*′ connected uniformly behind these. The sections 1*a*′, 1*b*′ and 1*c*′ are insulated from each other by the two gaskets 39 and 40 and are secured together with the bolts 41 and 42.

The hot bore 20' connects the hot portion of the displacer bore 5' with the upper right hand side of the power bore 19'. The hot bore 20' is generally horizontal in the elevation view and runs normal in the plan view.

The cold bore 21' connects the cold portion of the displacer bore with the left hand side of the power bore 19'. The cold bore 21' is generally diagonal in the elevation view and normal in the plan view.

A single shaft 43 and two bearings 25 support the rotors 4' and 23' within their respective bores.

A front plate 2' and rear plate 3' are required at both ends of the engine block 1, to pressure seal the engine. The gaskets 44' and 45', respectively, assure a positive leak-free seal. One retaining flange 17 carries the shaft seal 18 which pressure seals the shaft 43 where it exits the engine.

The power rotor 23' has a through bore into which the shaft 43 closely fits, which provides full support for the rotor. The power vanes 26' closely fit into the slots 26'' within the rotor as in the radial flow design.

All other detail features of the axial flow design are the same as in the radial flow design.

What is claimed is:

1. A pressurized gas rotary Stirling cycle engine comprising an engine block divided into three nearly equal sections, two large parallel bores disposed within the said engine block, multiple small bores disposed at right angles to the said large bores which freely communicate with the said two large parallel bores to form a continuous gas circuit, a small base rotor-half eccentrically located within one of the two large parallel bores, a large half-cylindrical displacer member in slidable association with the said small base rotor-half, bearing means for the slidable association of the two half displacer rotor members, bearing means disposed on the outside of the said large half-cylindrical displacer member in rolling association with one of the said two large parallel bores, circular regenerator bores uniformly disposed within the said large half-cylindrical displacer member, fine metallic filament uniformly disposed within the said circular regenerator bores, shaft and bearing means for the said small base rotor-half supported within one of the said equal sections of the said engine block, a power rotor containing multiple radial slots, multiple slotted power vanes in close sliding association with the said multiple radial slots of the said power rotor, an output shaft secured within the through center bore of the said power rotor and supported by offset and in-line bearings disposed within the said engine block, two end plates secured to and enclosing the said engine block, sealing means disposed within one of the said end plates where the shafts protrude from the said engine block.

2. A pressurized gas rotary Stirling cycle engine according to claim 1, in which the said engine block contains multiple fluid cooling bores axially disposed between the said two large parallel bores, heating means for one side of the said engine block.

3. A pressurized gas rotary Stirling cycle engine according to claim 1, in which the said shafts protruding from the engine block are each provided with large spur gears, a third spur gear meshes with the two said spur gears and is supported by an idler shaft mounted to the said engine block, a cover housing disposed over the gear assembly and secured to the said engine block.

4. A pressurized gas rotary Stirling cycle engine according to claim 1, in which the said multiple slotted power vanes are provided with rectangular end half-lapped sealing elements which are closely fitted into the said slots, the said two large parallel large bores are provided with baked on dry film lubrication.

5. A pressurized gas rotary Stirling cycle engine according to claim 1, in which the said engine block is provided with thermal insulation material disposed between the said three nearly equal sections, external bolting means provided to join the said three sections into one module.

6. A pressurized gas rotary Stirling cycle engine comprising an engine block divided into three nearly equal sections, two of said nearly equal sections disposed side-by-side with the third disposed centrally behind the first two, two large in-line bores disposed at both ends of the said engine block, two small bores are diagonally disposed and in free communication with the said two large in-line bores, to form a continuous gas circuit, a small base rotor-half eccentrically located within one of the said two large in-line bores, a large half-cylindrical displacer member in slidable association with the said small base rotor-half, bearing means for the slidable association of the two half displacer rotor members, bearing means disposed on the outside of the said large half-cylindrical displacer member in rolling association with one of the said two large in-line bores, circular regenerator bores uniformly disposed within the said large half-cylindrical displacer member, fine metallic filament uniformly disposed within the said circular regenerator bores, shaft and bearing means for the said small base rotor-half supported with the said side-by-side equal sections of the engine block, a power rotor containing multiple radial slots, multiple slotted power vanes in close sliding association with the said multiple radial slots of the said power rotor, a through center bore within said power rotor for the said shaft and bearing means, two end plates secured to and enclosing the said engine block, sealing means disposed within one of the said end plates where the shaft protrudes from the said engine block.

7. A pressurized gas rotary Stirling cycle engine according to claim 6, including metallic cooling fins secured to one of the said side-by-side nearly equal sections, heating means secured to the other one of the said side-by-side nearly equal sections.

8. A pressurized gas rotary Stirling cycle engine according to claim 6, including multiple one piece U-shaped sealing elements closely fitted within the said slotted power vanes, spring means acting between the said multiple slotted power vanes and the said multiple radial slots of the power rotor.

9. A pressurized gas rotary Stirling cycle engine according to claim 6, in which one of the said nearly equal sections contains multiple axial fluid cooling holes disposed uniformly around half the periphery of one of the said two large in-line bores.

10. A pressurized gas rotary Stirling cycle engine according to claim 6, in which the said nearly equal sections are separated by thermal insulation material, external bolting means provided to join the said three nearly equal sections.

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U.S. Cl. X.R.

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