

Jan. 13, 1970

D. A. KELLY

3,488,945

ROTARY STIRLING CYCLE ENGINES

Filed April 24, 1968

3 Sheets-Sheet 1

FIG. 1

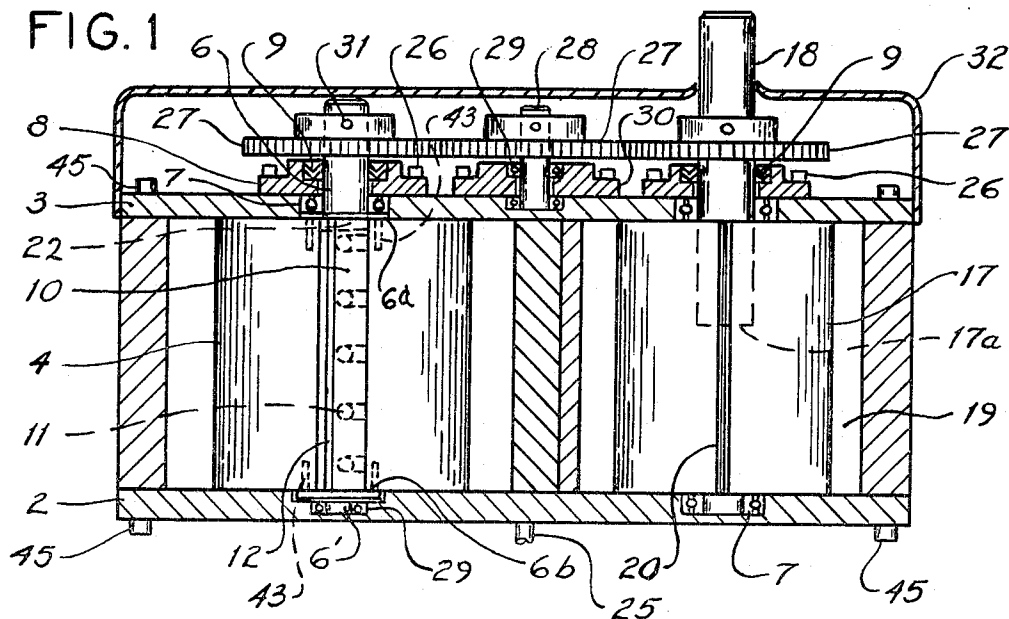
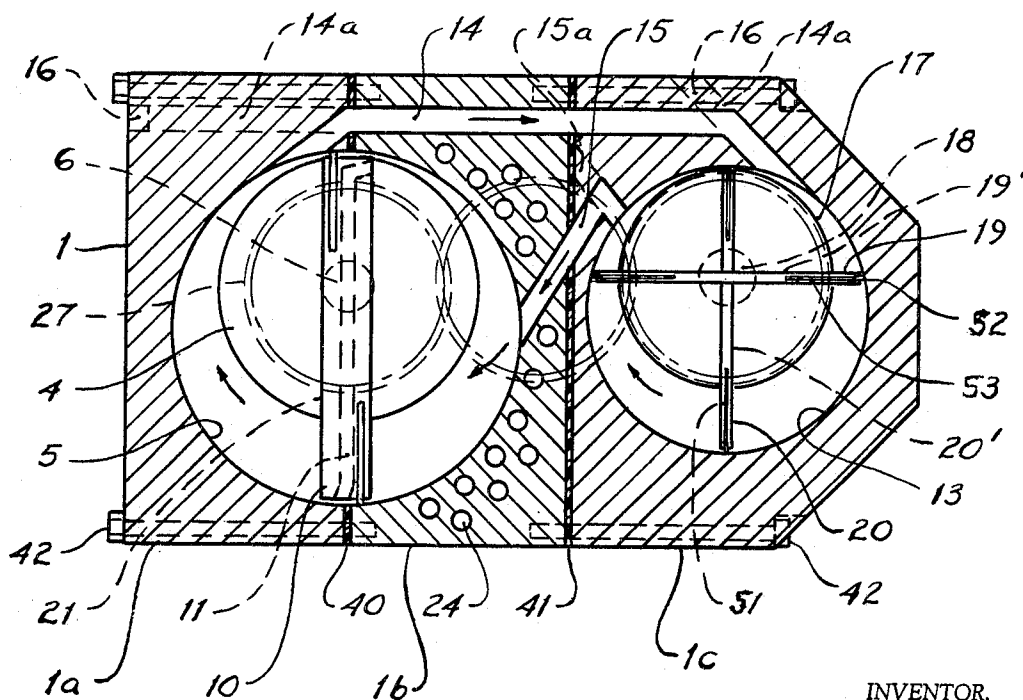


FIG. 2



INVENTOR.

Donald A. Kelly

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D. A. KELLY

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FIG. 3

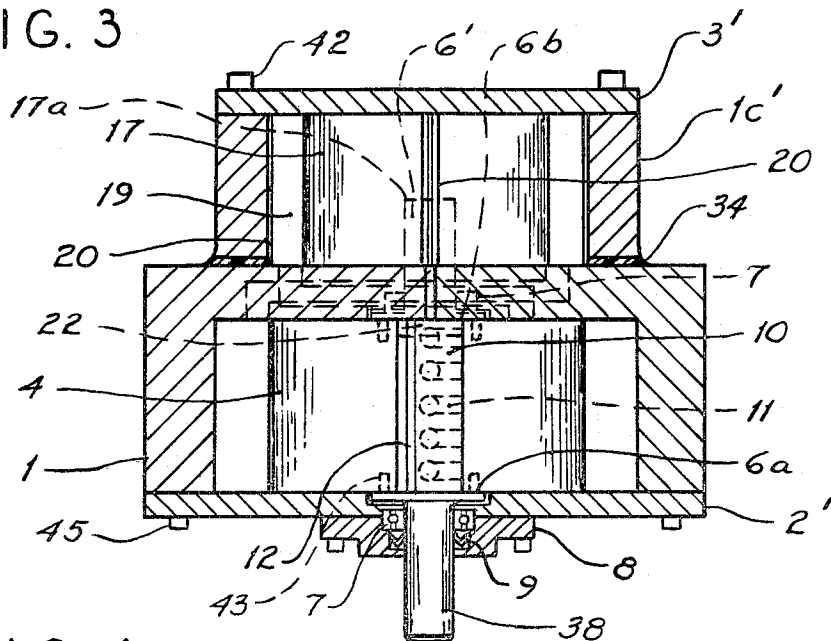
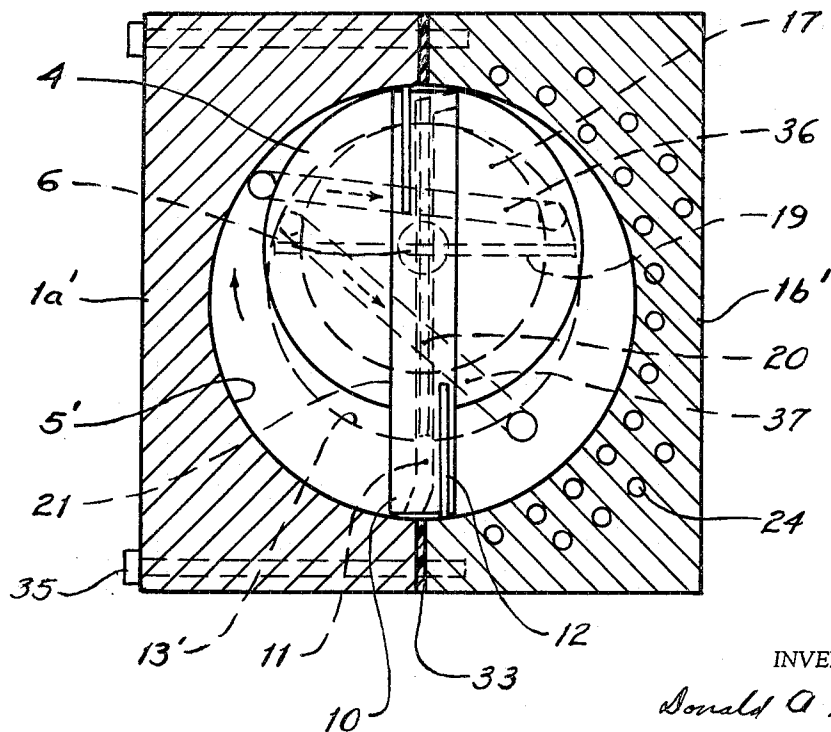


FIG. 4



INVENTOR.

Donald A. Kelly

Jan. 13, 1970

D. A. KELLY

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FIG. 5

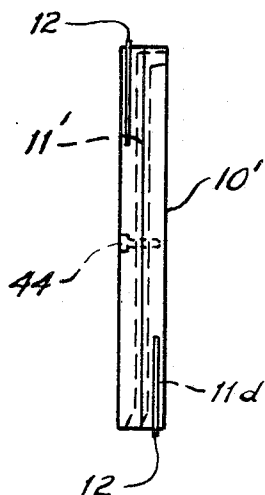


FIG. 6

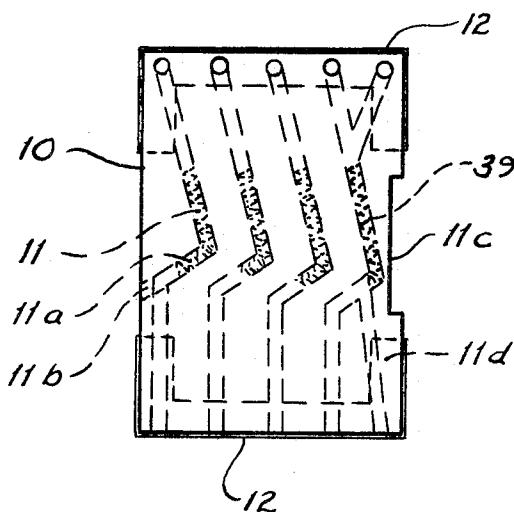
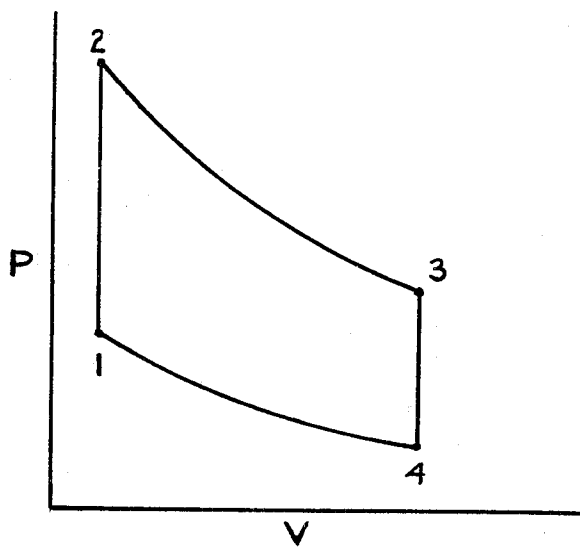


FIG. 7



INVENTOR.

Donald A. Kelly

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3,488,945

ROTARY STIRLING CYCLE ENGINES

Donald A. Kelly, 58—6 69th Place,
Maspeth, N.Y. 11378

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9 Claims

ABSTRACT OF THE DISCLOSURE

The rotary Stirling cycle engine comprises two, simple eccentric rotor and vane assemblies interconnected, with one serving as the gas displacer stage and the other as the power stage.

The arrangement closely duplicates the functioning of the reciprocating Stirling engines but with the advantage of fewer and simpler rotary components. The wide, sliding displacer vane has internal, zig-zag regenerator bores for efficient heat energy conservation.

This invention relates to a new pressurized Stirling cycle engine including both axial and radial gas flow versions.

This rotary engine is a modification of my prior Patent No. 3,370,418 with the basic components and gas flow paths essentially the same. The major difference in this engine is that the displacer stage rotor and vane compress the gas in a similar manner to that of the reciprocating engine. The normal phase heating/expansion and cooling/compression of the gas must be obtained in order to effectively complete the cycle.

Various types of pressurized reciprocating Stirling engines are known and being developed and while they are efficient all are somewhat hampered by the necessity of dual, co-axial pistons, connecting rods and rotary conversion means.

The classic Stirling closed cycle engine is basically an externally heated engine in which a sealed constant volume gas is alternately heated and cooled in a displacement volume to produce pressure pulses on the power piston.

The cycle consists of heating the gas which expands isothermally to perform work, and then cooling the gas which is compressed isothermally to return to the original starting point. 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 gases contact the cold wall area which results in a slight loss of efficiency.

The compression ratio of the Stirling engine is inherently set at about 2.5 to 1 by the basic proportions of the components, so that the working pressure level determines the power-to-displacement-to-weight proportions of the engine. A ratio of about 2 horsepower per cu. in. has currently been established by the reciprocating engines which is quite attractive for many applications.

In this rotary design, an eccentric rotor and 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, convenient engine module with a minimum of interconnecting ducts or bores. The axial gas flow is not as efficient as in the radial flow arrangement since the gas

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movement is at right angles to the direction of rotation.

In the radial flow or parallel bore arrangement the hot expanding gases are centrifugally directed by the rotating displacer vane into the power stage where they act on and rotate the power rotor vanes. During the cold half-cycle the contracting gas has an outward flow effect in the cold duct and thereby provides a pull on the power vanes.

This arrangement is somewhat more efficient than the axial flow type, since there is a natural, direct radial flow from one stage to the other with no inefficiency due to directional change and port cutoff.

The displacement of the gas from the hot to cold side of the displacer stage is accomplished by a wide displacer vane which is free to move radially as the displacer rotor revolves. The displacer vane is a free fit within the displacer bore in a similar manner to that of the reciprocating displacer piston within its displacer cylinder.

The displacer vane arrangement provides two equal gas cavities within the displacer bore which are alternately heated and cooled as the displacer vane sweeps around the cylinder. The cycle is completed when the cooled gas is returned to the starting point of the heating phase.

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 engine 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 vane must also be reversed when the direction of rotation is reversed, since it has inlet port orientation.

The adoption of modular construction 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 remaining one for the power stage. The three would be insulated from each other, keyed and thru bolted to form the complete module.

For convenience in manufacturing the hot and cold transfer bores would be bored in the single block before the two separation cuts are made. The starting points of the bores would be plugged where necessary to maintain the gas circuit integrity. This method of construction would greatly reduce manufacturing time and cost without any trade-off in the basic cycle efficiency.

The axial flow module would also consist of three sections, but in a different arrangement to suit the operating type. The hot and cold sections would be connected side by side with the power section behind these and connected to both. The three would be keyed and insulated from each other to maintain the necessary thermal isolation.

The displacer vane would be provided with zig-zag rephases. Inlet ports would be located at one extremity of each bore on the face of the vane and outlet ports on the opposite extreme end, so that effective transfer from one thermal half to the same half is maintained.

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 vane sweeps into the hot section, stores it as the vane sweeps through the cold section and releases it as the vane just enters the hot section.

It must be noted that the total length of the zig-zag regenerator bores within the displacer vane must be equal to half the port arc circumference so that a balanced thermal storage and transfer will be achieved.

The engine, as a closed cycle machine must be provided with a high temperature dry film lubricant and low-friction seals so that no internal circulating oil system is required. Effective long-life lubrication appears to be a salient problem and considerable testing remains to be done in this area.

It is an object of the invention to achieve a simple, efficient rotary Stirling engine with a minimum of inexpensive 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 adopting new regeneration and thermal saturation techniques.

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 with no fluid lubrication necessary.

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 1 is a top section view 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 front view of the displacer vane,

FIGURE 6 is a side view of the displaced vane, and

FIGURE 7 is the P-V diagram for the engine cycle.

Referring to the drawing in detail:

The engine block 1 is divided into three sections which are nearly equal in volume. Section 1a is the hot section, 1b is the cold section and 1c is the power section. The sections are insulated from each other by the two gaskets 41 and 40, and secured together with the bolts 42. The front plate 2 and the rear plate 3 are secured to the engine block 1 by the screws 45.

The displacer rotor 4 closely fits and revolves in the displacer bore 5 in section 1a and is supported by the shaft 6 and stub shaft 6'. The two rotor bearings 7 and 29 support the displacer rotor and shaft 6 within the engine block 1 and plates 2 and 3. The retaining flanges 8 carry the shaft seals 9 which pressure seal the shafts in the engine block. The retaining flanges 8 are secured to the rear plate 3 with the screws 26, with liquid sealant used to make a pressure tight seal between the retaining flanges and the rear plate 3.

The displacer rotor 4 has a diametrical slot 21 through its center which closely guides the radial motion of the displacer vane 10. The slot 21 nearly divides the rotor 4 in half except for the tie piece 22 at one end. The shaft 6 has a base flange 6a which is secured to the rotor 4 end by the screws 43. The stub shaft 6' also has a base flange 6b which is secured to the opposite end of the rotor 4 by the screws 43.

The displacer vane 10, is provided with internal regenerator bores 11, which are offset with the side bores 11a sealed with the threaded plugs 11b. A side notch 11c provides clearance for the tie piece 21' of the rotor 4. The ends of the displacer vane 10 are provided with slots 11d into which the rectangular seals 12 are fitted.

The power bore 13 is located in the engine block section 1c and is connected to the displacer bore 5 by the multiple hot transfer bores 14 and multiple cold transfer bores 15. The entrance bores 14a and 15a are sealed with the threaded plugs 16. The hot and cold transfer bores 14 and 15 are offset from each other, so that the bores do not intersect and cause leakage.

The power rotor 17 closely fits and revolves in the power bore 13 and is supported by the output shaft 18. The two rotor bearings 7 support the power rotor and the output shaft 18 within the engine block 1 and plates 2 and 3.

The two interacting power vanes 19 and 20 are closely fitted into corresponding slots 19' and 20' within the power rotor 17, and may freely move radially within these slots. The power rotor 17 has a blind bore 17a which provides clearance for the power vanes 19 and 20.

The power vanes 19 and 20 are provided with slots 51 at the ends and along the sides into which the rectangular seals 52 and 53 are closely fitted. The sealing arrangement for each vane consists of two long rectangular seals 52 at the vane ends and four side rectangular seals 53 at the vane sides. The ends of the adjacent seals are half-lapped so that they interlock to form a continuous sealing surface.

The engine block section 1b contains the multiple liquid coolant holes 24 axially arrayed around the interior periphery of the displacer bore 5. The coolant holes 24 must cover nearly 180 degrees of the bore and must not be less than twenty in number to assure adequate cooling for the cold section. The entrance portion of the coolant holes 24 will be threaded to receive the connecting tubes 25 which are connected to the manifold.

Three identical spur gears 27 are secured to the shaft 6, 18 and the idler shaft 28. 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 28 is supported by the two ball bearings 29 and flange 30. The flange 30 is secured to the rear plate 3 by the screws 26. The gears are locked on their respective shafts by the pins 31. A snap-on cover 32 encloses the gear assembly to provide dirt exclusion and isolation of these components.

In the axial design, the engine block 1, contains the displacer bore 5' at one end and the bore 13' at the opposite end with both on the same centerline. All the rotating elements of the radial engine version are the same for the axial design since the functioning is identical. The hot section 1a' is connected side-by-side to the cold section 1b' with the power section 1c' connected to each of these. The sections 1a', 1b', 1c' are insulated from each other by the two gaskets 33 and 34 and secured together with the bolts 35 and 42.

The hot bore 36 connects the hot portion of the displacer bore 5' with the upper right hand side of the power bore 13'. The hot bore 36 is generally horizontal in the elevation view and runs diagonally in the plain view.

The cold bore 37 connects the cold portion of the displacer bore with the upper left hand side of the power bore 13'. The cold bore 37 is generally diagonal in both views.

A single shaft 38 and two bearings 7 support the rotor 4 and 17 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 33 and 34, respectively, assure a positive leak-free seal. One retaining flange 8 carries the shaft seal 9 which pressure seals the shaft 38 where it exits the engine.

The power rotor 17 has a blind bore 17a which provides clearance for the interacting power vanes 19 and 20, which is the same as in the radial flow design.

An alternate displacer vane 10' would consist of two identical halves split longitudinally and joined with multiple small screws 44. This arrangement would allow the zig-zag regenerator bores 11' to be made continuous with no side bores or plugs, so that manufacturing requirements are eased. The regenerator bores 11' are provided with fine regenerator filament uniformly arranged within the bores.

What is claimed is:

1. A pressurized gas rotary Stirling cycle engine comprising an engine block divided into three sections, two parallel large 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 displacer rotor containing a wide diametrical slot, a wide displacer vane freely fitted into one of the said parallel large bores and slidably associated with the said wide diametrical slot, multiple non-linear regenerator bores uniformly disposed within the said wide displaced vane, regenerator fine filaments uniformly disposed within the multiple non-linear regenerator bores, a flanged short shaft disposed at each end of the said displacer rotor and each supported by a bearing offset and in-line within one of the said parallel bores, the said displacer rotor disposed nearly tangent to one of the said parallel bores at one point, a power rotor containing two axial slots at right angles to each other and a blind center bore, two slotted intermeshing power vanes slidably associated with the said two slots within the said power rotor, an output shaft secured within the said blind center bore of the power rotor and supported by offset and in-line bearings disposed within the said engine housing, two end plates secured to and sealing the said engine block, sealing means disposed within one of 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 multiple non-linear regenerator bores uniformly disposed within the said wide displacer vane are nearly equal in length to one-half the circumference of the said wide displacer bore, multiple parts corresponding to and intersecting the said regenerator bores uniformly disposed on the face at one end of the said wide displacer vane, anti-friction end seals are disposed within corresponding slots at the ends and sides of the said wide displacer vane.

3. 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 parallel large bores, heating means for one side of the said engine block.

4. 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 a large spur gear, 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 disposed over the gear assembly and secured to the said engine block.

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

6. A pressurized gas rotary Stirling cycle engine comprising an engine block divided into three nearly equal sections, two in-line large bores disposed within the said engine block, two small bores are in free communication with the said two in-line bores to form a continuous gas circuit, a displacer rotor containing a wide diametrical slot, a wide displacer vane freely fitted into one of the said in-line bores and slidably associated with the said wide diametrical slot, multiple non-linear regenerator bores uniformly disposed within the said wide displacer vane, regenerator filament uniformly disposed within the multiple non-linear regenerator bores, a flanged shaft disposed at each end of the said displacer rotor and each supported by a bearing offset and in-line within one of the in-line large bores, the said displacer rotor is nearly tangent to the bore at one point, a power rotor containing two axial slots at right angles to each other and a blind center bore, two slotted intermeshing power vanes slidably associated with the said two slots within the power rotor, one of the said flanged shafts at one end of the displacer rotor secured within the said blind center bore of the power rotor and supported by offset bearings disposed within the said housing block, the said power rotor is tangent to its bore at one point, two end plates secured to and sealing the said engine block at each end, sealing means 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, in which the said engine block contains multiple fluid cooling bores axially disposed at one side of the said engine block.

8. A pressurized gas rotary Stirling cycle engine according to claim 6, in which the said engine block is provided with thermal insulation means between the said divided three nearly equal sections, external bolting means provided to join the said three sections into one module.

9. A pressurized gas rotary Stirling cycle engine according to claim 6, in which the width of the said wide displacer vane is equal to from one-eighth to one-quarter the diameter of the said displacer rotor, the said wide displaced vane being fitted with multiple anti-friction end seals disposed at the extreme ends and sides.

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55 CARROLL B. DORITY, JR., Primary Examiner

U.S. Cl. X.R.