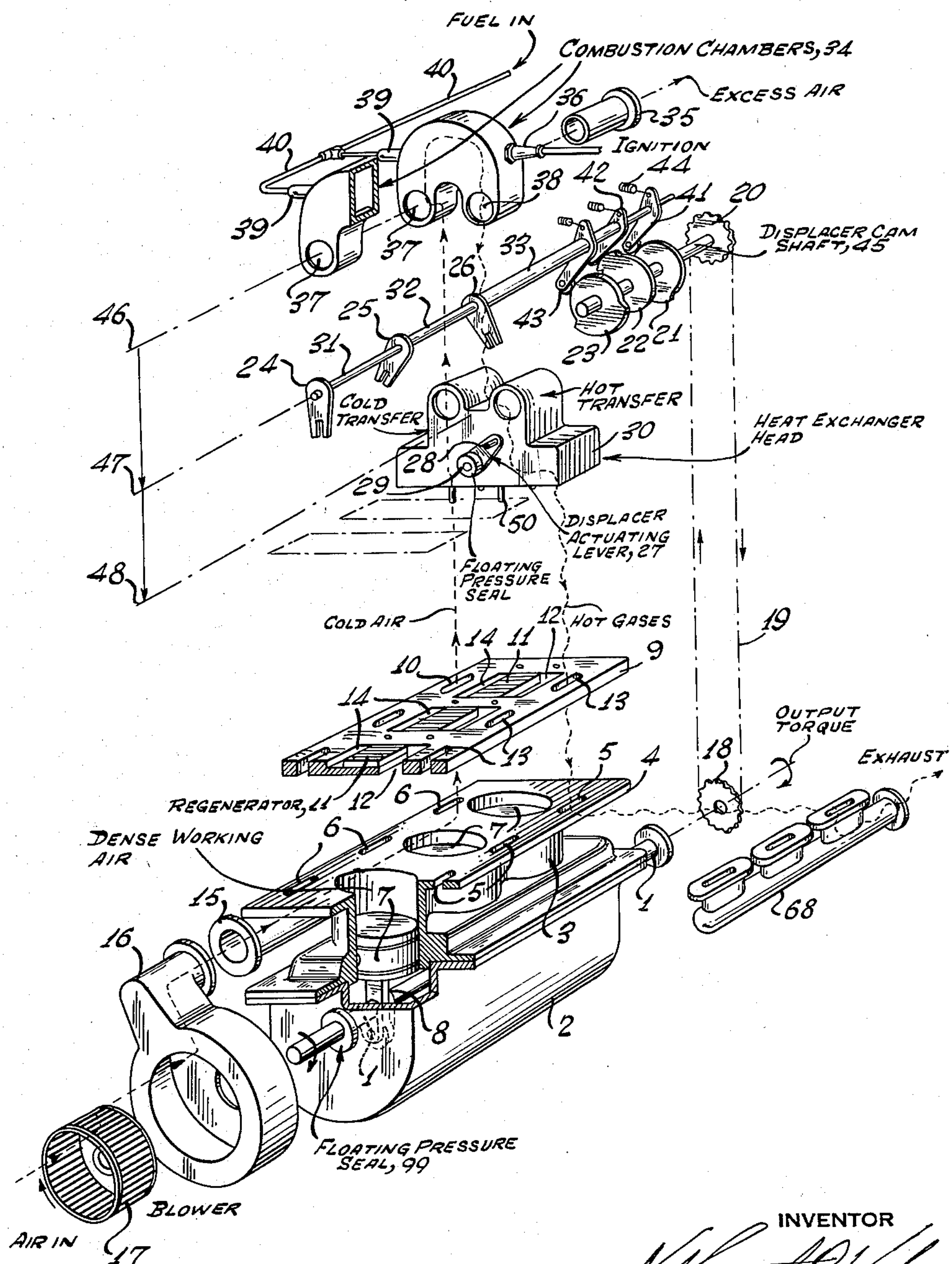
July 4, 1961 N. B. WALES 2,990,681

HIGH COMPRESSION EXTERNALLY FIRED LAMINAL DISPLACER ENGINE

Filed Jan. 10, 1961 6 Sheets-Sheet 1

Fig. 1.



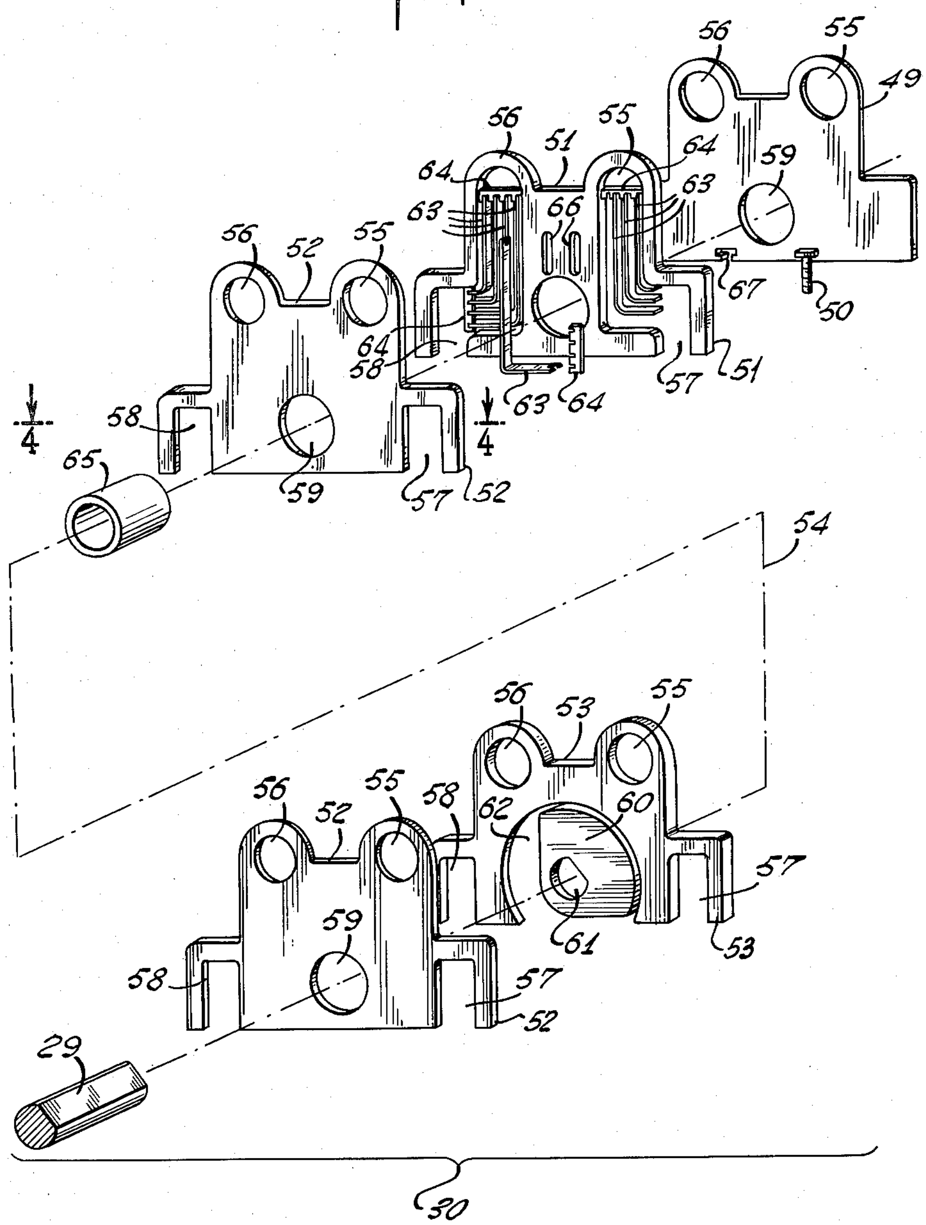
INVENTOR

Nathaniel B. Wales

HIGH COMPRESSION EXTERNALLY FIRED LAMINAL DISPLACER ENGINE

Filed Jan. 10, 1961 6 Sheets-Sheet 2

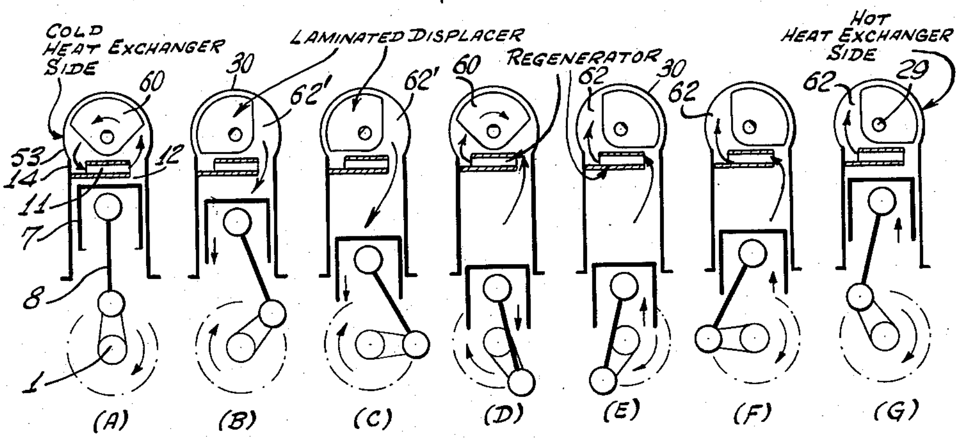
Fig. 2.



INVENTOR

Nathaniel B. Wales

Fig. 3.



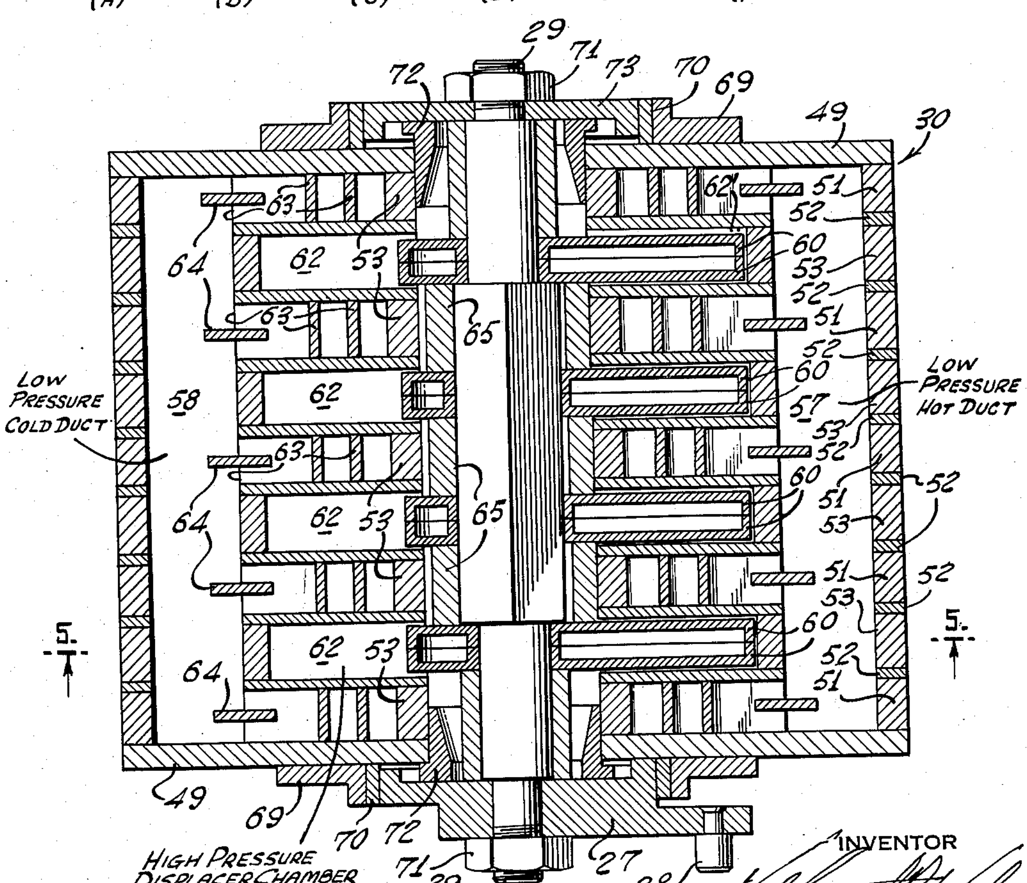
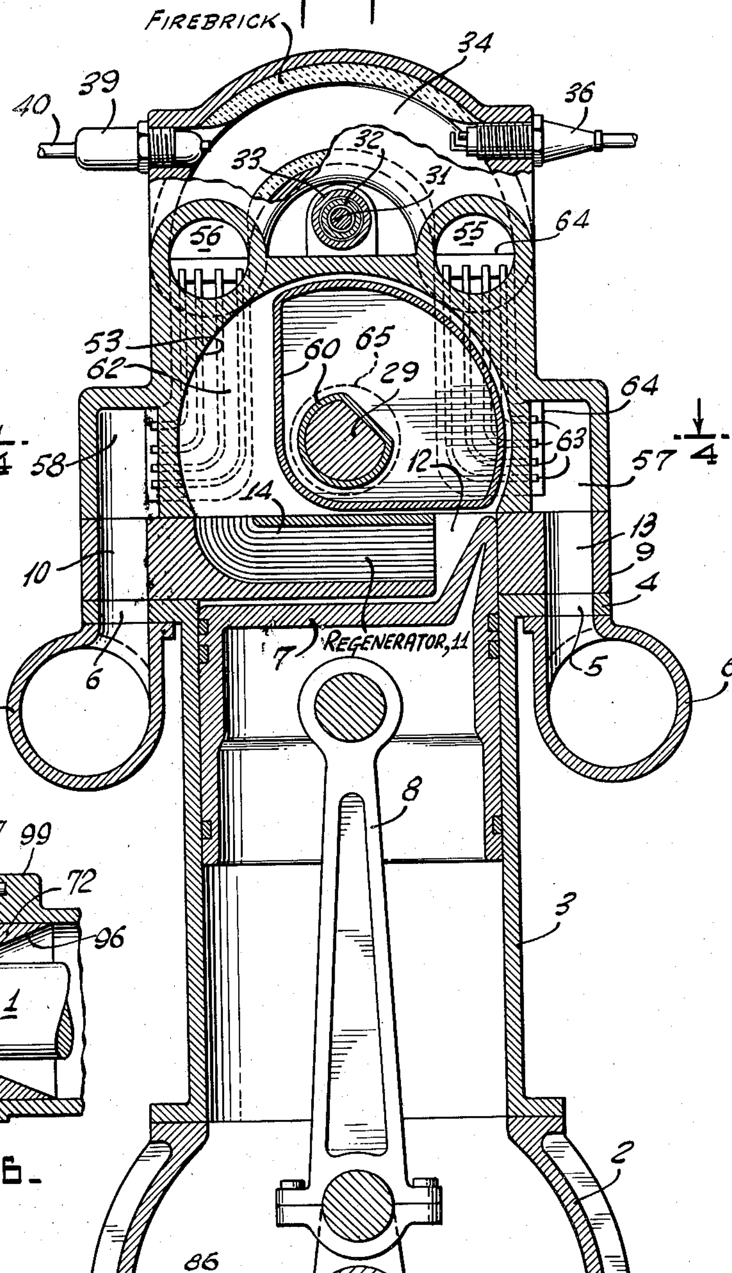


Fig. 4.

INVENTOR
Nathaniel B. Wales

Fig. 5.



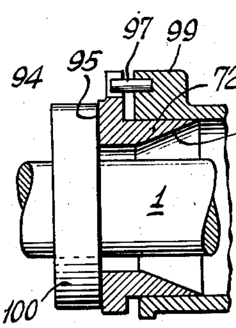
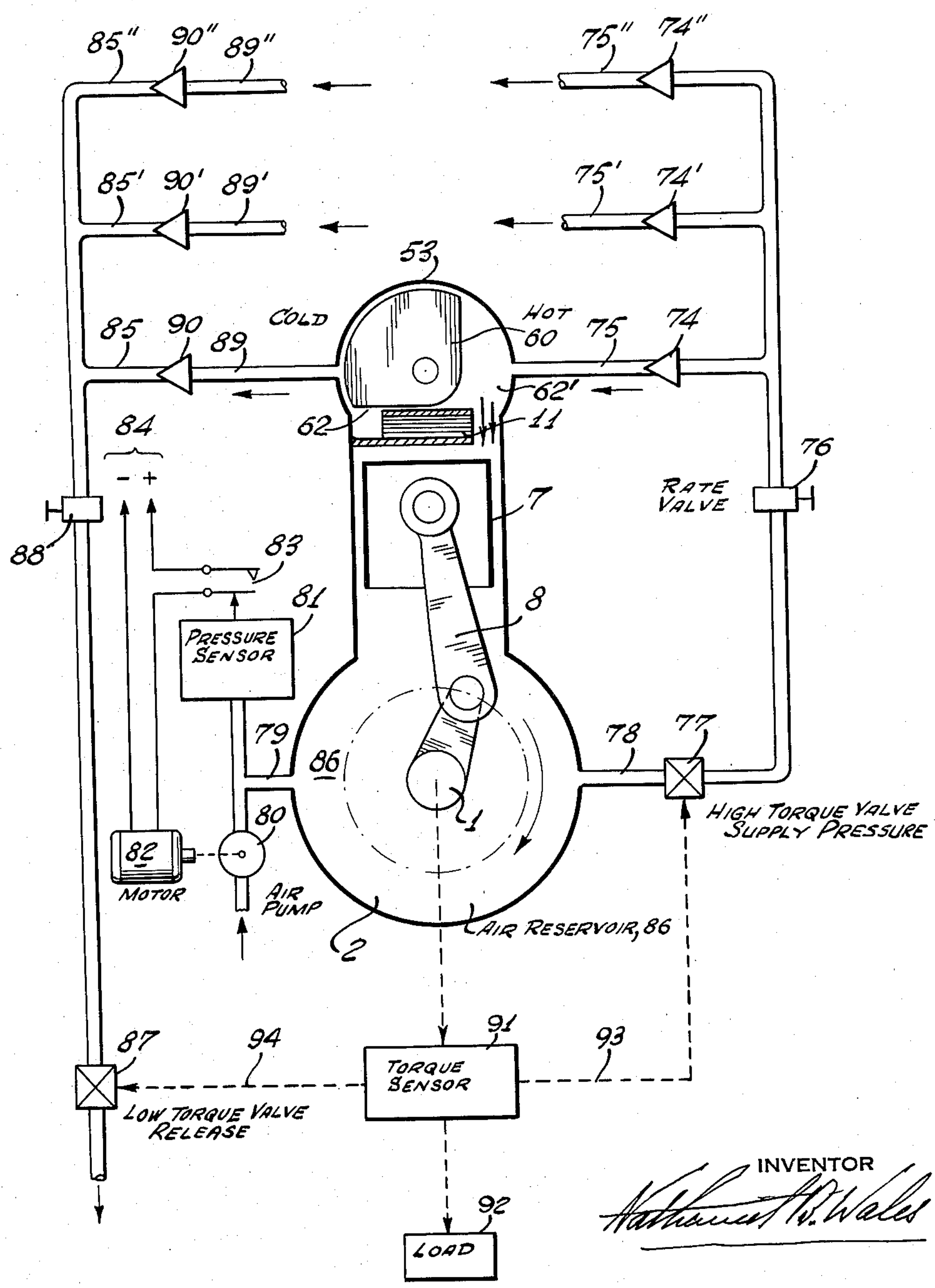


Fig. 6.

INVENTOR
Nathaniel B. Wales

Fig. 7.



INVENTOR
Nathaniel B. Wales

HIGH COMPRESSION EXTERNALLY FIRED LAMINAL DISPLACER ENGINE

Filed Jan. 10, 1961 6 Sheets-Sheet 6

Fig. 7A.

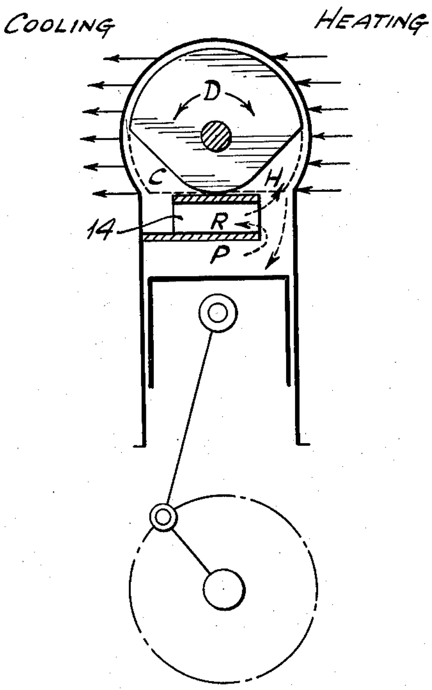


Fig. 7B.

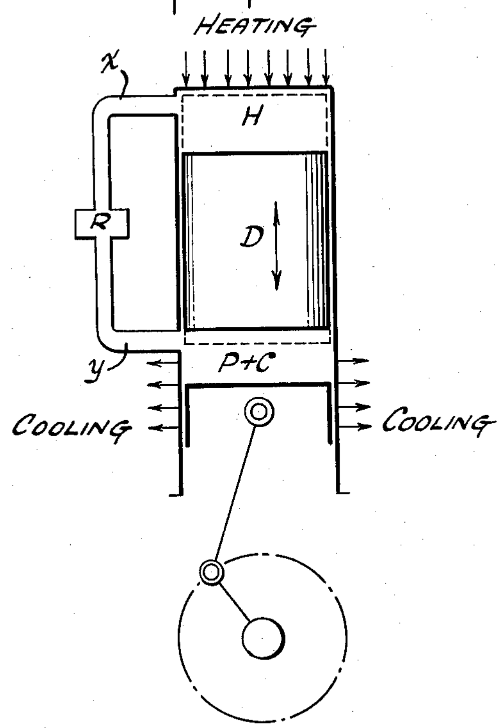
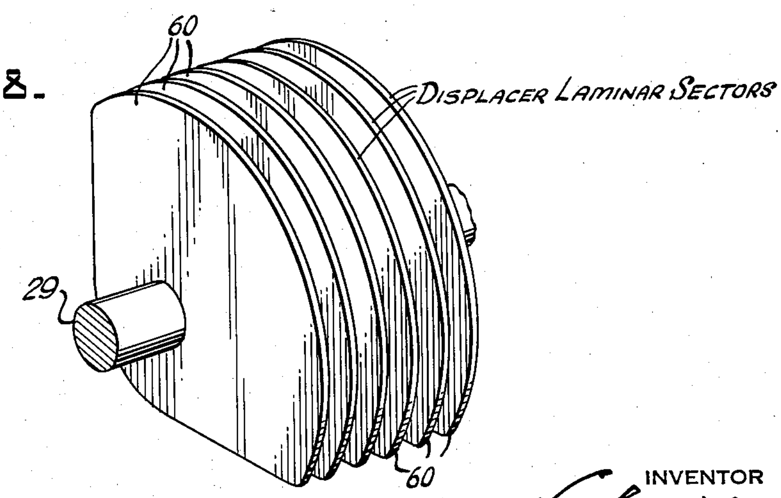


Fig. 8.



INVENTOR

Nathaniel B. Wales

United States Patent Office

2,990,681

Patented July 4, 1961

2,990,681
HIGH COMPRESSION EXTERNALLY FIRED LAMINAL DISPLACER ENGINE

Nathaniel B. Wales, 649 Hill St., Southampton, N.Y.

Filed Jan. 10, 1961, Ser. No. 89,597
22 Claims. (Cl. 60—24)

This invention relates to an improved form of an externally fired dense air heat engine of the generic Stirling type, which provides a high compression ratio. In this engine dense air or a gas as a working-fluid is moved by the oscillatory angular rocking displacement of a laminated rotatable displacer member between alternate thermal contact with stationary hot and cold walls which interleave the extremities of the laminations of this displacer at the respective terminations of its displacement.

The rocking motion or oscillation of the laminated displacer of my invention is so coordinated with the reciprocation of a piston in a working cylinder volume, that, at the peak of the piston's compression, due to the preferred intermittant movement of the displacer's action, the dense working-fluid such as air or a gas is ejected from the cold clearance volume through a heat regenerator into the hot clearance volume; whereas during the power stroke, the dense hot working-fluid flows from the hot clearance volume through a very short direct duct into the working piston volume.

It is evident that the cylinder head as will be seen from following detailed specifications is composed of a plurality of separate parts as formed for practical manufacture and ease of assembly purposes but which contains and houses the heating and cooling elements, the displacer as well as the regenerator in a compact operative assembly.

Now it may thus be seen that my invention utilizes four separate active chambers, namely, a cold clearance volume chamber, a regenerator chamber, a hot clearance volume chamber, and a working cylinder volume chamber.

This is in contradistinction to the conventional Stirling engine design which utilizes only three chambers since its cold clearance volume chamber is identical with its working cylinder volume chamber.

In the present Stirling engine art, the early impractical weight and volume requirements for a given power output have been overcome by the use of up to 100 atmospheres base pressure to increase the density, and hence the thermal capacity, of the working fluid, so that modern Stirling dense air engines can now successfully complete with and excel steam and internal combustion engines in their power per unit weight ratios, and in thermal efficiency.

The conventional to date Stirling dense working-fluid displacer consists of a hollow cylindrical closed ended piston which reciprocates linearly along an axis which is coaxial with its working piston and cylinder. Because of the fact that such engines combine their cold clearance volume with the working cylinder volume, the motion of this coaxial displacer is contrived to follow the piston downward during the power stroke so as to shield the expanding hot dense air working-fluid from premature contact with the cold walls of the combined cylinder chamber and cold clearance volume.

The consequence of this arrangement is that the total minimum clearance volume of such an engine must be nearly equal to the piston displacement, because, in fol-

lowing the piston down during this shielding action, the coaxial displacer sweeps out behind it nearly the same volume as the working piston displaces.

This large minimum clearance volume, in turn, determines that the compression ratio of such coaxial displacer engines can never be much greater than 2.5 to 1, resulting in an excessively high "base" pressure requirement.

The present invention overcomes this compression ratio limitation by separating the cold working-fluid clearance volume from the working piston volume, thereby making the motion of the displacer relatively independent of the motion of the working piston, and allowing compression ratios of 5+ to 1, or more, to be achieved.

The consequent benefits are greater thermal efficiency and lower required base pressures. In addition, my invention teaches a highly developed lamination of the displacer so as to increase the ratio of the area of heat transfer to the volume of the heat transfer chamber.

These spaced apart laminal disks are adapted to intermesh with conforming stationary heat transfer surfaces which greatly increase the efficiency of heating air or a gas by forcing it into a film during heat transfer periods.

Further, by utilizing a rotary displacer member it is possible to use a pair of balanced floating rotary seals to give mechanical control access from the unpressurized exterior of the engine to the interior of the pressurized displacer chamber.

It is evident that air or a gas can be utilized in this engine as its working fluid.

It is an object of this invention to provide a design for externally fired dense-gas or air engines which will permit high compression ratios.

A second important object is to provide a laminated geometry of displacers of dense-air or gas engines which will provide an improved ratio of temperature transfer area to volume for displacer chambers.

A third object is to provide a displacer design which will permit its timing control through rotary seals.

A fourth object is to provide a floating rotary seal which will have low friction and minimum wear under high fluid pressures.

A fifth object is to provide a pressure control system for dense air engines which will make the engine torque responsive to the load.

A sixth object is to reduce the base-pressure as required for high output by substantially increasing the engine's compression ratio.

A seventh object is to utilize an enlarged cylinder-head as the container for the displacer, heating and cooling elements and regenerator so as to obtain compactness and internally short intercommunicating ducts between operative chambers.

Other objects are implicit in the accompanying specifications and claims.

In the drawings:

FIG. 1 is a partially exploded isometric view of the preferred three cylinder embodiment of my invention;

FIG. 2 is an exploded isometric view in part of the heat exchanger head of FIG. 1 showing one hollow type displacer lamination;

FIGS. 3*a* to 3*g* are a sequential series of mechanical schematic diagrams showing the timing of the engine;

FIG. 4 is a plan view through 4—4 of FIG. 2;

FIG. 5 is a section in elevation through 5—5 of FIG. 4;

FIG. 6 is a sectional elevation of a sealing structure having floating balance.

FIG. 7 is a schematic diagram of a preferred form of base pressure control in response to the load experienced by the engine;

FIG. 7*a* is a schematic diagram of the working-fluid circuit of the separate operative chambers of my invention namely C, H, R and P in contradistinction to the operative chambers seen in FIG. 7*b*;

FIG. 7*b* is a schematic diagram of the working-fluid circuit of the operative chambers of the conventional Stirling cycle engine whereby chambers P and C are combined and their functions are operative in space P+C;

FIG. 8 is a view in perspective of the displacer proportions as taught in the present invention.

Referring to FIGS. 1 through 5 it may be seen that the cylinder mono-block **3** contains three pistons **7** which are coupled to crankshaft **1** by connecting rods **8** at 120° phase relationship. Crankshaft **1** is journalled in crankcase **2** and emerges at each end therefrom through rotary floating pressure seals **99**. Cylinder mono-block **3** is secured and gasketed to crankcase **2** so as to form a constant volume air pressure reservoir **86** therewith (see FIG. 5). Cylinder mono-block **3** has an upper flange **4** provided with cooling air inlet apertures **6** and exhaust apertures **5** which communicate with and are sealed to cooling air intake manifold **15** and exhaust manifold **68** respectively.

A blower wheel **17** secured to shaft **1** operates in blower housing **16** to supply cooling air and combustion-air to the intake manifold **15**.

A regenerator housing plate **9** is provided to form an upper closure for cylinder mono-block **3** and a base to which the three heat exchanger rotary displacer heads **30** are secured to and sealed, see FIG. 1 and FIG. 4. Apertures **10** and **13** in plate **9** (see FIG. 1) continue the intake and exhaust ducts **6** and **5** of flange **4** respectively.

The three regenerators **11** (see FIG. 5) each consist of a large number of metal wires which are stacked in parallel array within the cavities **14** of regenerator housing plate **9** so that they present a large area of heat transfer either to hot dense working-fluid passing up from cylinder block **3** via duct **12** and through the interstices between the parallel regenerator wires **11** into the cold displacer clearance volume **62** of a heat exchanger section-head **30** (see FIG. 3), or conversely, to cold dense air passing down from one of the cold displacer clearance volumes **62** through the interstices of the parallel regenerator wires **11** and back up through duct **12** into the opposite displacer hot clearance volume **62'** during the displacer transfer which takes place when a piston **7** is substantially at the top of its stroke. In the former case, the warm dense air passing from the cylinder to the cold space leaves behind a large portion of its heat by heating the regenerator wires, while in the latter case, the cold compressed gases passing from the cold space recover the stored heat from the regenerator wires before passing into the hot displacer space **62'** of head **30** (see also FIG. 3).

Each displaced heat exchanger head **30** may be seen in FIGS. 2, 4, and 5 to be formed by a stack of plates **49, 51, 52, 53, 52, 51, 52, 53, 52, 51, 52, 53, 52, 51, 52, 53, 52, 51, 49** which are furnace brazed together in a jig to form a series of four interconnected high pressure flat D shaped displacer chambers **62** and **62'** which are interleaved on one side with five low pressure cooling heat exchange chambers **58**, and on the other side with five low pressure heating heat exchange chambers **57**, see FIGS. 2, 4 and 5.

Each low pressure heat exchange chamber, whether hot or cold, is provided with a plurality of heat transfer fins **63**, these are spaced at each end by interlocking combs **64**, and serve to support and space the thin heat separator plates **52**. These in turn separate the low pressure heating and cooling medium chambers from the high pressure working-fluid displacer chambers **62** and **62'**.

By means of this construction a rigid, light-weight, efficient heat exchange manifold is capable of being manufactured from low cost stampings. Exchanger heads **30** are secured to plate **9** and cylinder mono-block flange **4** by means of bolts **50**. In FIG. 2, the apertures **66** in plates **51** are to obstruct direct flow-of-heat from the hot to the cold sides thereof.

The displacer laminations **60** are hollow for low heat capacity and conduction, being each formed of two fan-shaped drawn shallow cups which are clamped together on a common shaft **29** between spacers **65** by nuts **71**. A flat on shaft **29** serves to key the congruent keyways **61** of the displacers **60** to shaft **29**.

As may be seen in FIG. 4, shaft **29** is provided with a bearing cup **73** at one end which is journalled in bearing bushing **70** of bearing flange **69** which, in turn, is secured to the end plate **49**.

The multiple hollow displacers as seen in FIGS. 4 and 5 have close clearances with the plates **52** and **53** which form the walls of the high pressure displacer chamber. It may be seen that when shaft **29** is rotated in bearings **70** by lever **27** as far as it can go in the clockwise direction as shown in FIG. 5, the major clearance volume **62** is on the cold temperature exchanger side so that the cold low pressure air being forced from manifold **15** through ducts **6** and **58** and out manifold **56** will abstract heat from the dense high pressure working fluid air in cold clearance volume **62** by allowing heat to flow through the thin separator plates **52** and ducting fins **63** into the cooling air stream.

Conversely, when the displacers **60** are displaced 90 degrees by the counter-clockwise rotation of shaft **29**, FIG. 3*a*, when piston **7** is near the top of its stroke, the cold compressed air in cold clearance volume **62** will be displaced downward through duct **14** and regenerator **11** into the newly created hot clearance volume **62'** via duct **12**. At this point heat will flow from the hot low pressure gases of combustion (which are flowing from combustion chambers **34** through ducts **55, 57, 13** and **5** into exhaust manifold **68**) past fins **63** and wall **52** so as to transfer heat into the dense high pressure working-fluid medium which has just entered the hot clearance volume **62**, see FIGS. 3*a*, 3*b*, 3*c*.

Due to the multiple laminar construction of this composite displacer **60**, the ratio of the total areas of the walls defining the clearance volumes **62** or **62'** to the total volume of the clearances **62** or **62'** will be large, thereby affording means for rapid heat transfer.

The timing mechanism for actuating the displacers may be seen in FIG. 1 in conjunction with the timing sequence of FIG. 3. The timing drive sprocket **18** secured to crankshaft **1** is coupled at unity ratio to the displacer cam shaft **45** by means of chain **19** and drive sprocket **20**.

The timing cams **21, 22** and **23** secured to cam shaft **45** are made to produce an oscillatory angulation of the displacer drive forks **24, 25** and **26** respectively about axis **47** through the cam follower levers **41, 42** and **43** which are respectively secured to the coaxial drive sleeves **31, 32** and **33**. Springs **44** are provided to cause levers **41, 42** and **43** to follow their corresponding cams.

Each drive fork **24, 25** and **26** embraces a corresponding drive pin **28** secured to a displacer drive lever **27**, so that by suitable design and phasing of the identical cams **21, 22** and **23** each displacer **60** is made to follow the timing sequence of FIG. 3 with respect to the motion of its piston **7**.

The balanced floating seal which permits the oscillation of the displacer shaft **29** without loss of pressure from the working dense air chambers may be seen in FIG. 4 to comprise the two annular shouldered sleeves **72** which can slide freely, in an axial direction in their openings in end plates **49** and plates **51** but which are forced in opposite directions to bear against and form a sealing axial contact with end cup 73 and lever cup 27 respectively. The inner wall of floating bushings 72 are tapered on the high pressure side to form a feather-edged radial seal.

This invention teaches that when the ratio of the projected annular area on which the high pressure fluid produces axial force such as the area numbered 96 in FIG. 6, to the annular area of axial contact between bushing 72 and plate 73 (or plate 27) is equal to approximately 2/3, a pressure balance or floating phenomenon takes place which allows the face of bushing 72 to slide freely on face 73 or 27 with negligible friction or wear and without leakage. It is surmised that this phenomenon is due to a distributed radial pressure gradient in the granular metal interface between bushing 72 and plate 27.

Pneumatic end thrust on shaft 29 is cancelled out by the use of identical floating seals 72 at opposite ends.

Crankshaft 1 is also provided with a similar balanced seal 99 (FIG. 1) at each end where it emerges from crankcase-reservoir 2.

In FIG. 6 the details of the crankcase seals 99 are shown. Shaft 1 is provided with a shoulder 100, at each end, against which an annular floating pressure seal ring 72 (identical to the rings 72 in the displacer shaft seals of FIG. 4) bears over the annular area 95. This is referred to as the "indirect" or floating area. The annular area on which the direct pressure to be sealed is exposed to is the projection of the conical area 96 on a plane normal to the axis of shaft 1. Pin 97 is fixed relative to crankcase 2 and engages a slot in ring 72 to prevent its rotation with shaft 1 so that area 95 forms the sliding seal. As before, I teach that the said projection of area 96 is to be ⅔ of area 95 to attain a floating low-friction sealing factor.

Referring to FIGS. 1, 2 and 5 it may be seen that the two combustion chambers 34 are positioned between the three heat exchanger heads 30 so that the through ducts 37 in chambers 34 together with the composite cooling air exhaust ducts 56 form a manifold from which the excess cooling air escapes by exhaust duct 35. This excess exhaust air can be used for auxiliary heating purposes.

A portion of the air entering ducts 5 and 58, after it has been heated in the process of cooling the working-fluid at fins 63, is allowed to enter the combustion chambers 34 where it is mixed with fuel supplied by fuel line 40 and injection nozzles 39 and ignited by spark plugs 36 to form hot products of combustion. Note should be made here that damper control of air for combustion is not shown.

These combustion products then flow out of combustion chambers 34 via ducts 38 and 55 to give up their heat to the hot displacement volumes 62′ via fins 63 and walls 52. The used combustion products then pass out to the exhaust manifold 68 via passages 57, 13, and 5.

The operation of my invention as seen in FIG. 3 is as follows:

At the top of the compression stroke of any piston 7 the working dense-air or gas is at maximum density and minimum temperature and is located nearly entirely in the cold clearance volume 62 (see FIG. 4). At this time the displacer 60 is driven by the cam shaft 45 to rotate 90° (FIG. 3*a*) in a counter-clockwise direction so as to force the cold dense air via duct 14 through the regenerator 11 where it picks up previously stored heat and thence passes via three junction manifolds 12 into the hot clearance volume 62′ which increases in volume simultaneously with the decrease of the cold clearance volume 62.

Due to the large heat transfer surfaces offered by fins 63 and the thin laminar walls 52, the regenerated warm dense working-fluid is rapidly heated and dilated by heat supplied by the combustion products generated in the combustion chambers 34. This expansion increases the pressure throughout the working-fluid, and work is done on the piston 7 and its load 92, see FIG. 7, as the piston moves downward (FIGS. 3*b*, 3*c*, and 3*d*).

Near the bottom of the power stroke the displacer 60 is now reversed in position by a cam-operated 90 degrees displacement in a clockwise direction (FIG. 3*d*) so that the hot clearance volume 62′ is blocked off, by using the hollow displacer segments as a heat shutter, and at the same time the cold clearance volume 62 is opened up to receive its working charge.

On the upward stroke (FIGS. 3*e*, 3*f*, 3*g*), the kinetic energy stored in the rotating parts of the engine are allowed to do back work in compressing the expanded warm dense air. As this compression proceeds, the working air is forced to pass through the regenerator 11 where it leaves behind a substantial portion of its heat and thence proceeds to enter the cold clearance volume 62 where it is further cooled through multiple walls 52 by the low pressure air supplied by blower 17. The net work representing the difference between that delivered during the expansion stroke and that abstracted during the compression stroke is then available for division between auxiliary requirements and useful output.

It may readily be seen in FIG. 5 how the working-piston's displacement of the present invention has permitted clearance volume proportions to attain a compression ratio on the order of 5+ to 1.

FIG. 7 illustrates the preferred means for maintaining and automatically controlling the average density of the working-fluid air in response to the load of the engine. In automative applications this disclosed control means can largely take over the function of a variable ratio transmission.

Since the three pistons 7 are equally displaced in phase by 120° on the crankshaft 1, it is evident that the volume of the pneumatic crankcase reservoir 86 is constant with crankshaft rotation.

The inlet duct 79 connects an air pump 80 driven by electric motor 82 and a pre-set pressure sensitive switch 83—81 to the reservoir 86. The motor 82, current supply 84 and pressure sensitive switch 83 are electrically connected to power an air pressure servo system which will tend to keep the air pressure in the reservoir at a high predetermined level. Duct 78 leads from reservoir 86 through control valve 77 and flow limiting rate-valve 76 to each of the one-way check valves 74, 74′ and 74″ which then each lead via ducts 75, 75′ and 75″ respectively to the hot clearance volumes 62′ of the three corresponding displacer heads 30.

Conversely ducts 89, 89′ and 89″ lead from the corresponding cold clearance volumes 62 through the one-way check values 90, 90′ and 90″ to the ducts 85, 85′ and 85″ thence exhausting into the air after passing through rate limiting valve 88 and the exhaust control valve 87.

A torque sensing mechanism 91 is made to generate (by means well known in the control art) the control signal 93 when the torque imposed on shaft 1 by load 92 exceeds a predetermined value. Signal 93 opens valve 77 which in turn allows working-fluid under relative high pressure from reservoir 86 to sequentially increase the base pressure in each of the three working cylinders as dictated by the cyclic pressure reversals across check valves 74, 74′ and 74″.

Conversely, torque sensing mechanism 91 is made to generate a signal 94 when the torque imposed on shaft 1 by load 92 decreases below a predetermined value. Signal 94 opens valve 87 leading to atmosphere thereby dropping the base density in each of the three working cylinders.

In this manner the speed and torque delivery capabilities of the dense air-engine have been automatically regulated in response to the load to change the base pressure which in turn determines the rate of heat transfer possible for a given piston pressure and results in a higher or lower M.E.P. as the case may be.

The diagrams in FIGS. 7a and 7b clearly distinguish the basic differences between my four chambered engine as shown in 7a and the well known three chambered coaxial displacer engine as shown in 7b. It is to be noted that the separate cold clearance volume C of my engine has no direct access to the piston chamber P whereas the piston chamber P and cold clearance volume C of the coaxial displacer engine are coincident. Because of this coincidence there can be no direct duct in 7b from the hot clearance volume H to the piston chamber P because such a duct would throw away heat by directly connecting C and H. In my device, however, the three way duct **12** directly connects H and P. It is because of the absence of a direct duct from H to P that the displacer D of 7b must follow the piston down in the expansion stroke thereby forfeiting a high compression ratio.

By providing a direct duct **12** from H to P my geometry permits the independent control of displacer and piston, thereby permitting high compression ratios.

It should also be emphasized that the multiple segmented displacer results in a maximum of heat transference with respect to its exterior dimensions. It also requires a minimum of clearance volume which permits a high ratio of compression. If each sector of the displacer, for an illustration, is one eighth of an inch in thickness (solid) as seen in FIG. 8 and a ten one-thousandth of an inch mechanical tolerance is provided on each side thereof, the laminar hollow heating or the cooling elements which intermesh with the displacer sectors as adjacent surfaces are only .127 of an inch apart. It is thus seen that very effective heat transfer conditions are brought into play, such as, the air or gas to be heated or cooled is forced into films and coincidently subjected to high velocity impingement in a compacted laminal structure as taught by the present invention.

By utilizing crankcase **2** as a working fluid reservoir it is seen that a desirable pneumatic cushioning effect on the pistons **7** is obtained to absorb their reversal inertias at the termination of their respective expansion strokes. A tissue oil vapor separator may be inserted in outlet pipe **78** in FIG. 7 to contain the oil vapor content in transit therefrom.

Referring to FIG. 1, it is quite evident to those skilled in this art that by well known manually adjustable mechanism, not shown, interposed between sprocket **20** and displacer cam shaft **45**, the displacer **60**, as seen in sequential positions, as in FIG. 3, during each revolution can be arbitrarily shifted in respect to the piston's **7** position, so that the engine's crankshaft **1** can be reversed in its operational direction of rotation. More specifically, in FIG. 5 the displacer **60** is shown in register with the heating surfaces. It would be, therefore, arbitrarily rotated by shaft **29**, 90 degrees anticlockwise into a similar registering position with the cooling surfaces and the engine would reverse its direction of rotation due to the shifting of cams **21**, **22** and **23** in FIG. 1 as dictated by the manipulation of the above mentioned manually adjustable mechanism.

What I claim is:

1. A dense-air or gaseous externally fired engine comprising a cylinder, a piston in said cylinder, a crankcase secured to the base of said cylinder, a crankshaft, means to mount said crankshaft in bearings in said cranckcase and means to connect said piston with said crankshaft to permit said piston to reciprocate in said cylinder while said crankshaft revolves, a cylinder head for said cylinder, an approximately cylindrical cavity in said cylinder head, a port in the base of said cavity in open communication with said cylinder, a displacer, bearing means to rotably mount said displacer in said cavity, the axis of said displacer mounting being approximately at right angles with the axis of said cylinder, said displacer composed of a connected series of in-line laminar disk-like elements, said elements spaced apart to permit a like series of laminar stationary hollow heating surfaces to inter-

mesh between said spaced apart disk-like elements of said displacer, said heating surfaces confined to a segment in said cylindrical cavity entirely on one side of the axis of said mounting, a like series of hollow cooling surfaces adapted to also mesh with said disk-like elements, said cooling surfaces occupying a similar position in respect to said displacer but entirely in an opposite segment on the other side of the axis of said mounting, means to oscillate and time the oscillation of said displacer in said bearings whereby said displacer elements mesh in register with said cooling elements during the expansion stroke of said piston and mesh in register with said heating elements during the compression stroke of said piston, and means to heat the interior of said heating surfaces and means to cool the interior of said cooling surfaces.

2. The text of claim 1 and automatic means to maintain a predetermined degree of air pressure in the clearance volume of said engine to serve as a pressurized working-fluid system.

3. The text of claim 2 and a load-torque indexing and actuating means to vary said pressure of said working-fluid of said engine to increase said pressure when said load torque on said engine increases and to lower said pressure when said load torque on said engine decreases.

4. The text of claim 1 and multiple segmented regenerator elements positioned in parallel planes as defined by the planes occupied by said hollow heating and said cooling surfaces so as to intermesh with said laminar disk-like elements of the displacer during their transit of oscillation, said regenerator elements occupying a space in length between the radial boundaries of said heating and said cooling surfaces and in an adjacent relation to said cylinder.

5. A dense working fluid high-compression heat engine comprising a cylinder, a cylinder head secured to the top of said cylinder, a piston in said cylinder, an output shaft, means to convert the reciprocation of said piston into revolutions of said out-put shaft, a chamber in said cylinder head, its axis of generation at right angles with the axis of said cylinder, said chamber substantially formed as a capital D, the vertical portion of the D being adjacent to and in parallelism with the top of said cylinder, a port in open communication between said chamber and said cylinder, a displacer, means to rotatably journal said displacer in said chamber on a shaft, said displacer formed of a plurality of laminar spaced apart sectors on said shaft, means to oscillate said displacer in a specific timed relation with the reciprocations of said piston, a plurality of hollow heating surfaces, said surfaces formed in projecting relation towards the axis of rotation of said displacer, a plurality of hollow cooling surfaces likewise positioned in a similar relation on the opposite side of the axis of oscillation of said displacer whereby when said sectors of said displacer are oscillated, said sectors assume an intermeshing relation only with said heating surfaces at one extremity of the displacer's oscillation and said sectors assume a similar relationship with said cooling surfaces at the other extremity of said oscillation and means to circulate a heating medium through said hollow heating surfaces and a cooling agent through said cooling surfaces.

6. The text of claim 5 and pumping means to maintain a predetermined pressure of a working fluid for said engine.

7. The text of claim 5 and a series of heat regenerative elements interposed in the base of said chamber in those spaces as defined by the plurality of spaces formed between the limiting radial boundaries of said heating and said cooling surfaces, said series of regenerators spaced apart to that degree one from the other to permit said displacer sectors to pass therebetween in the course of the oscillation of said displacer.

8. A dense working-fluid externally fired engine comprising a cylinder, a cylinder-head therefor, means to secure said cylinder head to said cylinder, a crankcase se-

cured to the base of said cylinder, an out-put shaft rotatably journaled in said crankcase, a reciprocating piston in said cylinder, means to convert the reciprocations of said piston into rotation of said output shaft, a displacer, said displacer formed in general contour as an approximate quadrant of a circle, a cavity in said cylinder head, a port in open communication connecting the adjacent portion of said cavity with the top of said cylinder, said cavity formed cylindrical with a flat circumferential portion in adjacent relation with the top of said cylinder to permit said displacer to be oscillated through an amplitude of approximately ninety degrees, bearing means to permit oscillation of said displacer in said cavity, means to oscillate said displacer, a heating surface, a cooling surface, means to heat said heating surface and means to cool said cooling surface, said heating surface positioned along a specific segment of said cylindrical cavity to bring it into register with said displacer at one extremity of said displacer's oscillation and said cooling surface so positioned as to also bring it into register with said displacer at the other extremity of said oscillation.

9. The text of claim 8 and dense working-fluid supply means and working-fluid exhaust means, said means in operative valved connection with the clearance volume of said engine to thereby increase or decrease the pressure of said working-fluid operative in said clearance volume in said engine respectively when a torque responsive means dictates an increase in the output torque from said engine and to decrease the pressure in the clearance volume of the engine when said torque responsive means dictates a decrease in the working-fluid in said clearance volume.

10. A dense working-fluid modified Stirling cycle engine comprising a cylinder, a piston, means to reciprocate said piston in said cylinder, an output shaft, means to convert said reciprocations of said piston into rotations of said shaft, a cylinder head, a chambered cavity in said cylinder head, a displacer, means to oscillate said displacer, said displacer journaled to oscillate in said cavity, hollow-formed heating surface, hollow-formed cooling surfaces, means to circulate a heating medium to heat the interior of said heating surfaces and to circulate a cooling agent to cool the interior of said cooling surfaces, said heating surfaces positioned within said cavity to register with said displacer at one extremity of its oscillation during every compression stroke of said piston, said cooling surfaces positioned within said cavity to register with said displacer at its other extremity of said oscillation during each expansion stroke of said piston, a port in open communication between said cavity and the top of said cylinder and means to maintain a working-medium under pressure in the clearance volume of said engine.

11. The text of claim 10 said displacer formed of a plurality of spaced apart laminar disks, said heating and said cooling surfaces so formed as to respectively intermesh when in registration between said plurality of disks of said displacer at every other extremity of each of its successive oscillations.

12. A dense-air working fluid externally fired engine comprising a cylinder, a reciprocating piston in said cylinder, an output shaft, means to convert the reciprocations of said piston into revolutions of said output shaft, a cylinder head, means to secure said cylinder head to said cylinder, a chamber in said cylinder head, a port connecting said chamber with the top of said cylinder, a displacer, said displacer composed of a plurality of laminar sectors, said sectors spaced apart and secured along a common shaft, means to journal said common shaft to permit said sectors thereon to be displaced through an amplitude of oscillation within said chamber, a plurality of stationary spaced apart heating elements, a plurality of stationary spaced apart cooling elements, means to position and to formulate said heating elements as positioned within said chamber to register in intermeshing relationship with said oscillative spaced apart sectors of said displacer during the major portion of the compression stroke of said piston in said cylinder and to likewise arrange said cooling elements within said chamber to come into registration in an intermeshing relationship with said oscillative spaced apart sectors of said displacer during the major portion of every expansion stroke of said piston and means to heat said heating elements and to cool said cooling elements.

13. The text of claim 12 and actuating mechanism to oscillate said displacer in an intermittent movement to thereby generate a dwell during said intermeshing relationship.

14. The text of claim 12 and automatic means to maintain a specific pressure of working-fluid in the clearance volume of said engine.

15. In an externally fired heat engine having dense air as its working fluid, the combination comprising: a cooling chamber; a heating chamber; a regenerator chamber; a working piston chamber; a thermal mass of substantial area within said regenerator chamber; a first port in said regenerator chamber; a second port in said regenerator chamber; first duct means interconnecting said cooling chamber and said first regenerator port; second duct means interconnecting said second regenerator port, said heating chamber and said working piston chamber; means to cool said cooling chamber; means to heat said heating chamber; a displacer member forming a bounding wall on one side of said cooling chamber and a bounding wall on a second side thereof of said heating chamber; a first reciprocating means to move said displacer member whereby with one direction of reciprocation to diminish the effective volume of said cooling chamber while increasing the effective volume of said heating chamber, and with the converse direction of reciprocation to diminish the effective volume of said heating chamber while increasing the effective volume of said cooling chamber; a working piston forming a boundary to said working piston chamber; a second reciprocating means reciprocated by said piston whereby to change the effective volume of said working piston chamber; and timing means interrelating said first and second reciprocating means whereby to diminish the volume of said heating chamber during the compression stroke of said piston and to diminish the volume of said cooling chamber during the expansion stroke of said piston.

16. In an engine according to claim 15; said displacer member being in laminar form interleaving said cooling means on one side and interleaving said heating means on another side.

17. In an engine according to claim 15; said first reciprocating means comprising oscillating means.

18. In an engine according to claim 15; said displacer member comprising hollow laminations.

19. In an engine according to claim 15; a reservoir chamber bounded at one area by said piston; means to maintain a constant volume of air in said reservoir chamber; means to maintain a substantially constant pressure in said reservoir chamber; and duct means having means responsive to the work done by said piston to transfer air from said reservoir to said working piston, heating, cooling, and regenerator chambers.

20. A high compression externally fired heat engine comprising a cylinder, a piston, a crankshaft, a crankcase, means to journal said crankshaft in said crankcase, means to transform the reciprocations of said piston in said cylinder into revolutions of said crankshaft, a displacer, means to journal said displacer, means to oscillate said displacer, a temperature regenerator, a cooling element, a heating element, a cylinder-head, means to secure said cylinder-head to said cylinder, a chamber in said cylinder-head, a first duct in open communication between said cylinder and said chamber, a second duct connected to a side-wall of said first duct and giving access to the cooling surfaces of said cooling element, said regenerator positioned within said second duct, means to operatively position in functioning relation one

with the other in said chamber; said displacer, said heating element and said cooling element, means to heat said heating element, means to cool said cooling element, means to supply a pressurized working-fluid to said chamber and means to time the displacements of said oscillating displacer in said chamber with the reciprocations of said piston in said cylinder.

21. The text of claim 20, the axis of said journaled oscillating displacer being approximately at right angles to the axis of said cylinder.

22. The text of claim 20 and said displacer composed of a plurality of thin laminal spaced-apart sectors, said sectors secured to the common axis of said oscillation.

References Cited in the file of this patent

UNITED STATES PATENTS

2,326,901	Thompson	Aug. 17, 1943
2,664,698	Van De Poll et al.	Jan. 5, 1954