

[54] **ROTARY PISTON ENGINE AND PISTON PHASING APPARATUS THEREFOR**

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[22] Filed: **Jan. 4, 1974**

[21] Appl. No.: **430,923**

[52] U.S. Cl. **418/36; 418/83**

[51] Int. Cl. **F01c 1/00; F03c 3/00; F04c 17/00**

[58] Field of Search **418/33, 35, 36, 38, 83; 123/8.47**

[56] **References Cited**

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[57] **ABSTRACT**

The apparatus controls relative motion between the rotary pistons of a rotary piston engine by the use of a curvilinear internal ring gear the contour of which is determined by the desired compression ratio of a variable volume defined between adjacent rotary pistons. Pinions, suitably connected to the rotary piston, traverse the contour of the curvilinear internal ring gear while constrained to move radially with respect to the axis of rotation and constrained in a constant angular relationship with respect to one another. The rotary piston shape disclosed uses centrifugal force to assist sealing engagement of compression rings with walls of the piston cavity.

Inlet and exhaust ports may be positioned such that the apparatus may be used to control piston movement of an internal combustion engine, a pump, a compressor, a turbine, or a motor.

14 Claims, 16 Drawing Figures

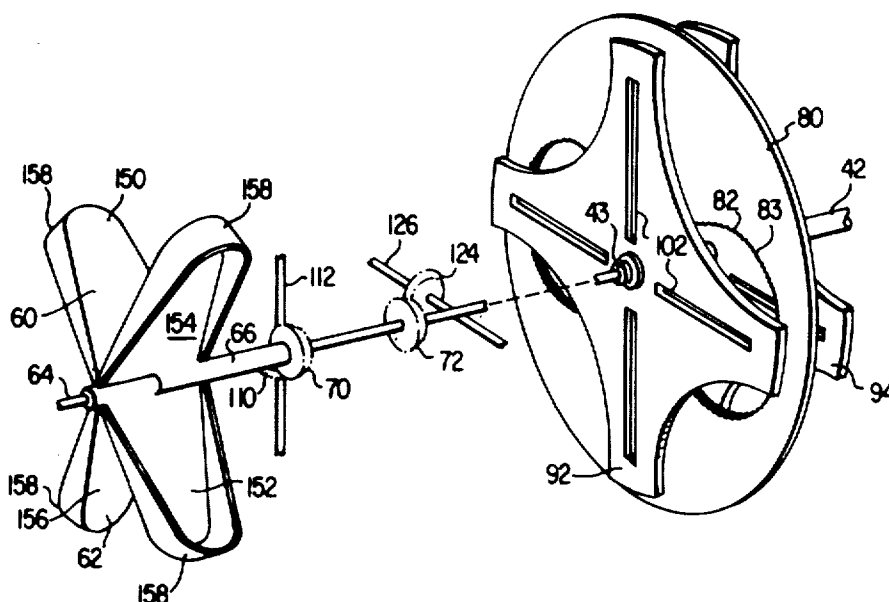
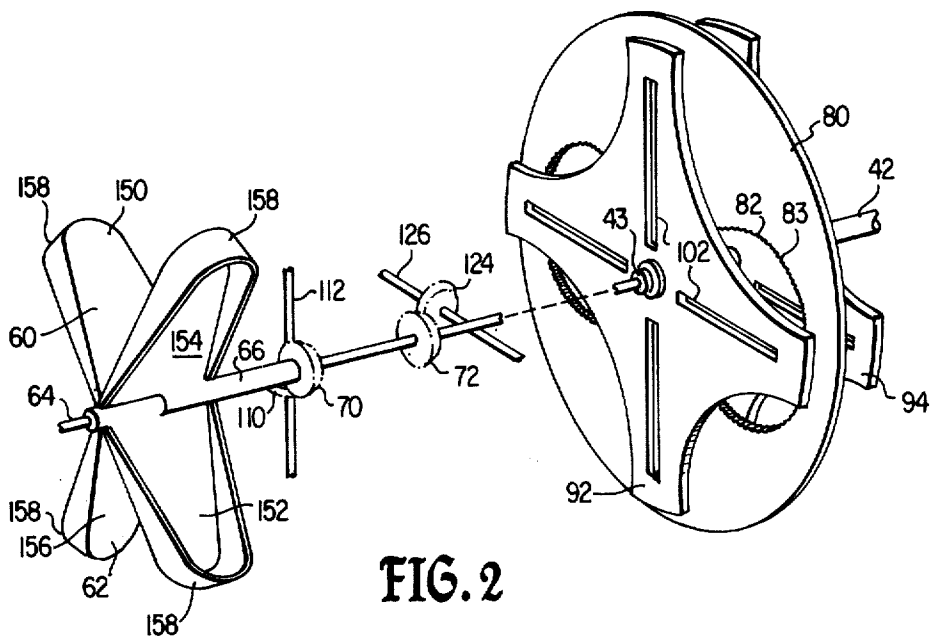
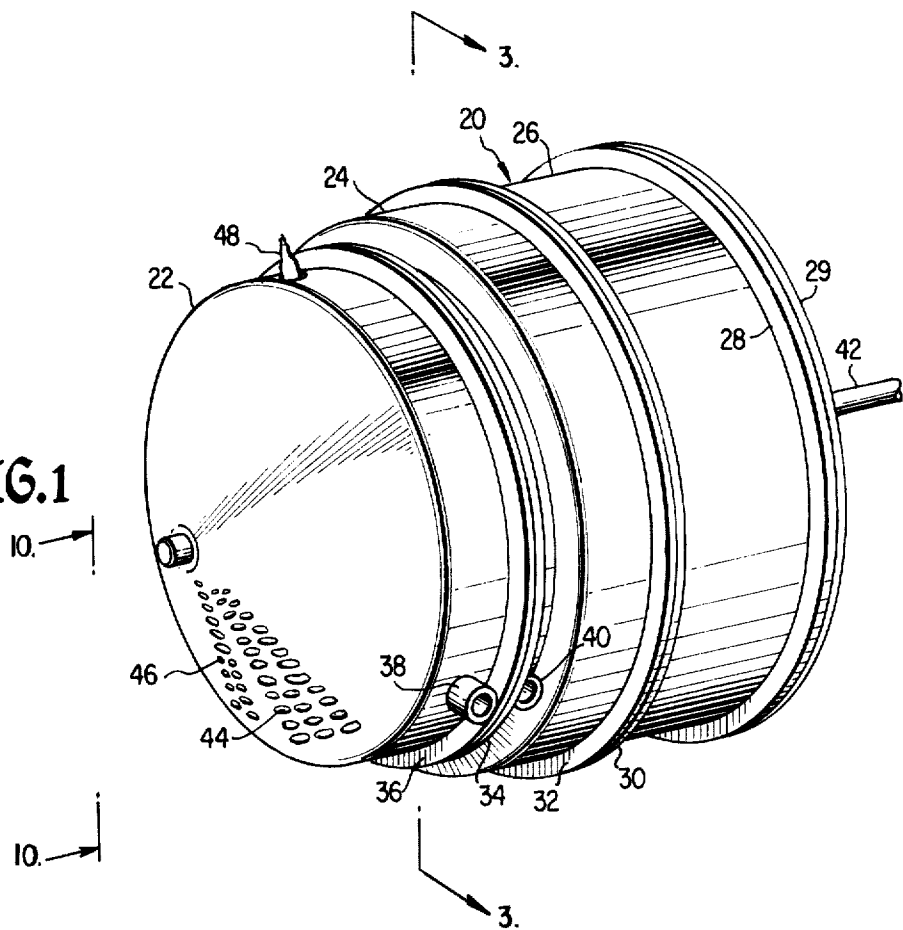


FIG. 1



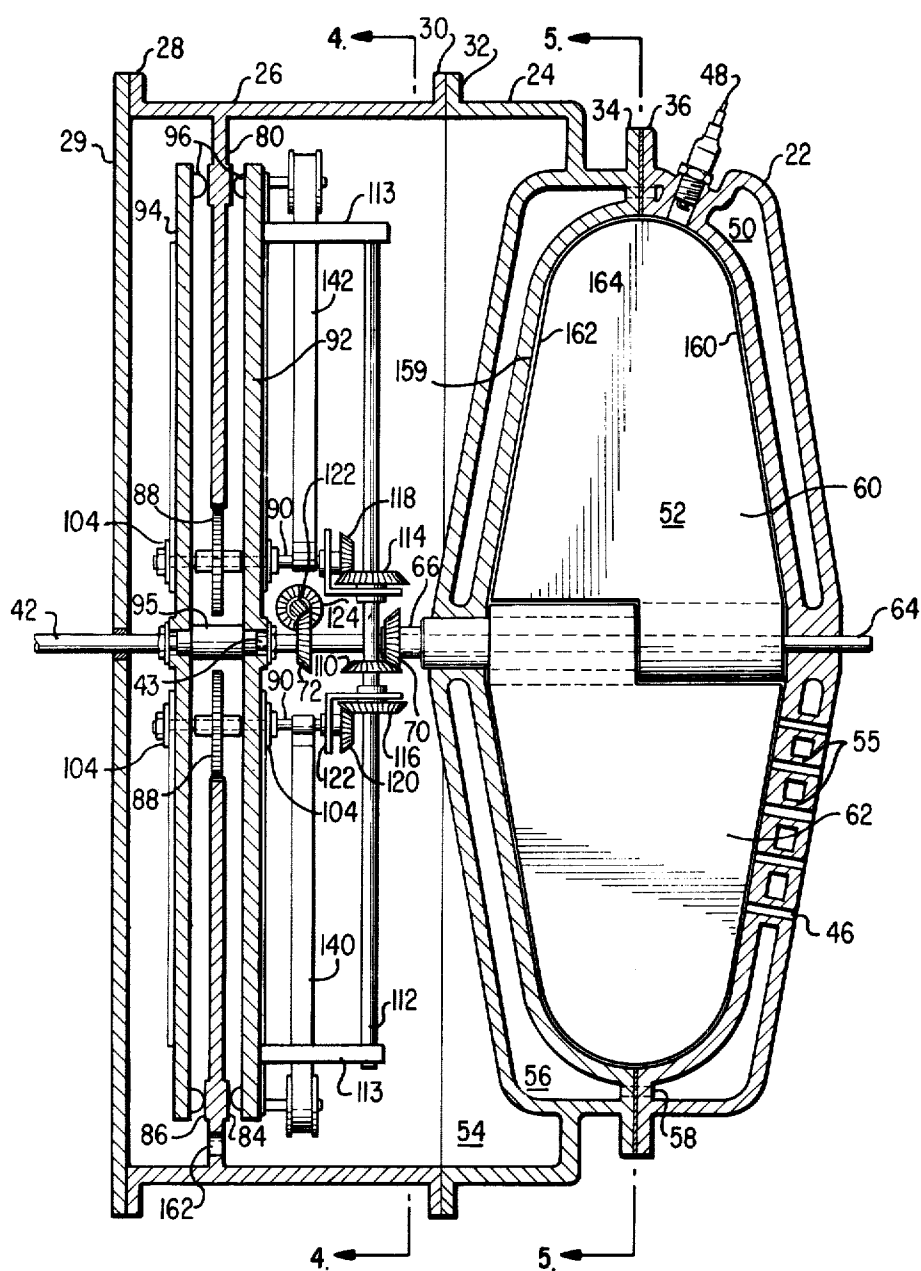


FIG. 3

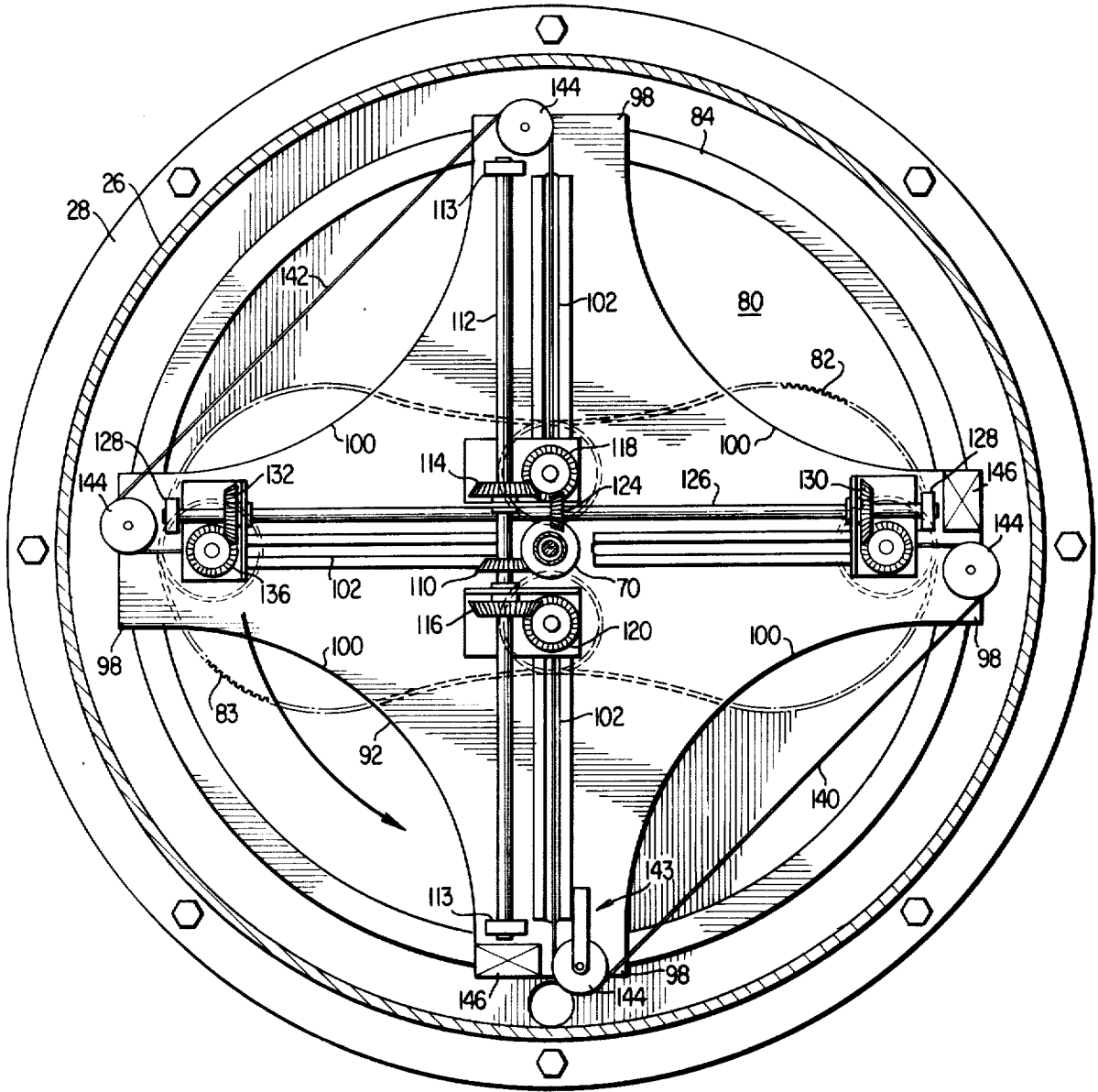


FIG. 4

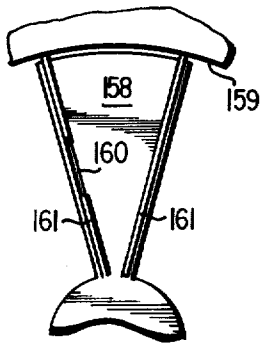


FIG. 11

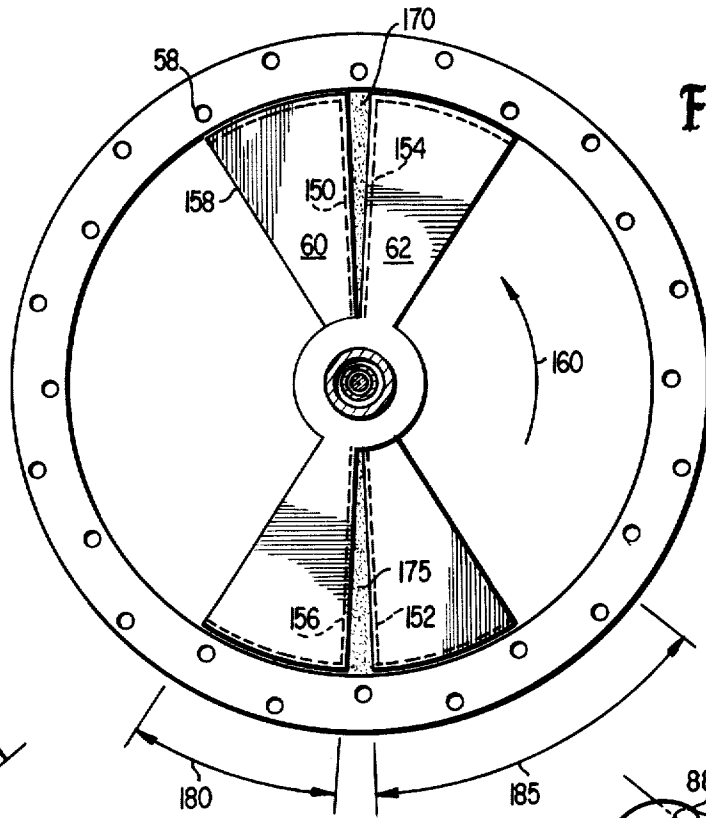


FIG. 5

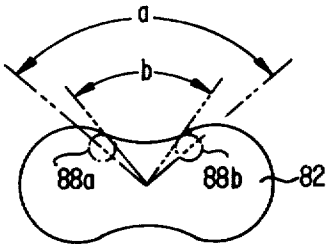


FIG. 5a

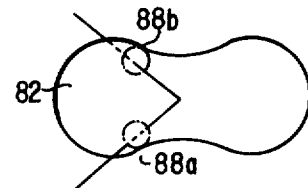


FIG. 6a

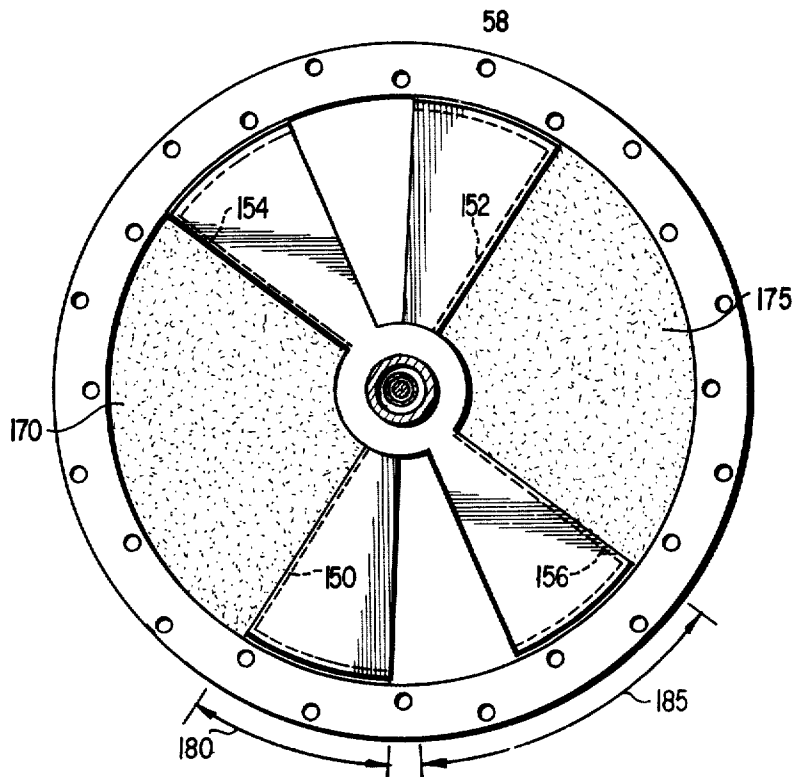


FIG. 6

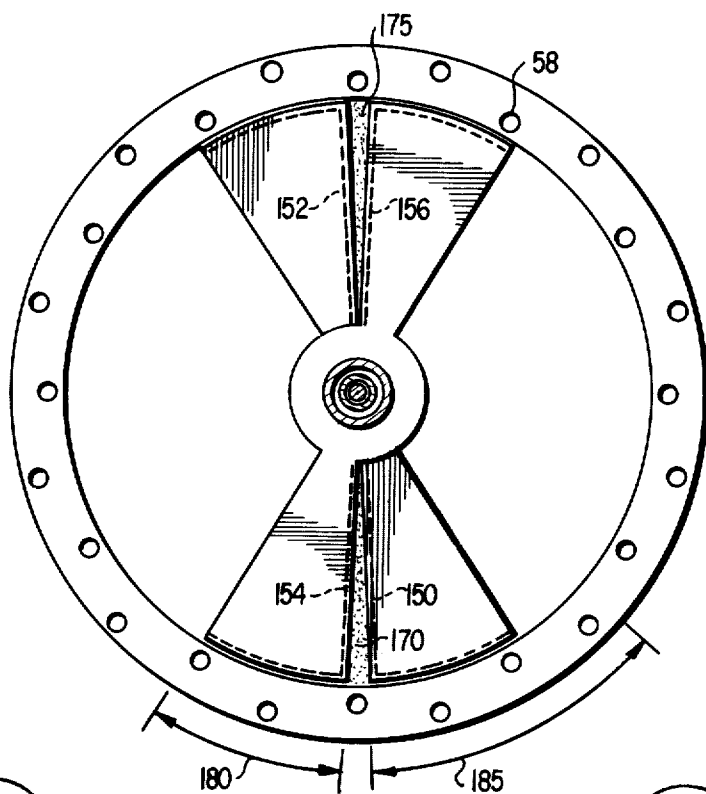


FIG. 7

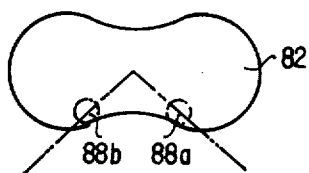


FIG. 7a

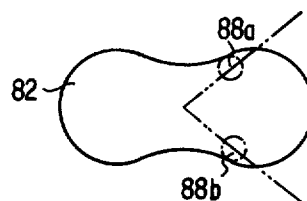


FIG. 8a

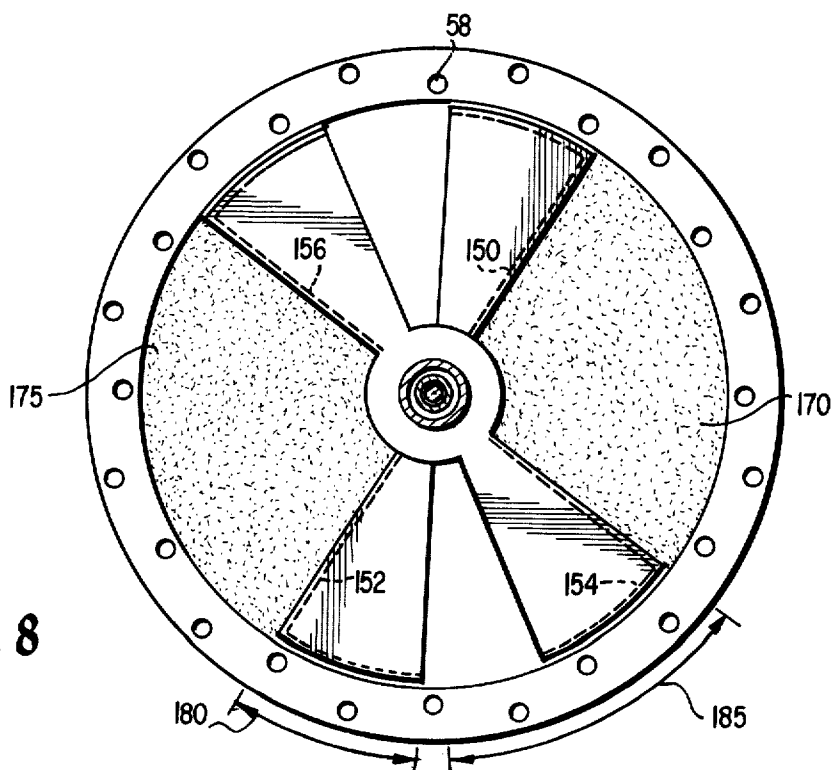


FIG. 8

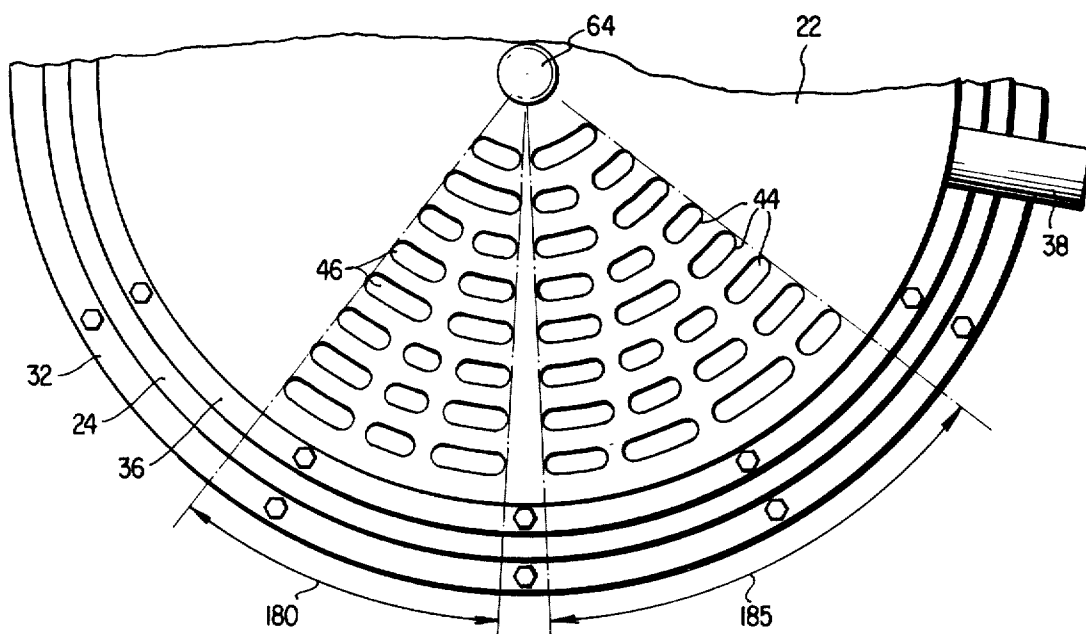


FIG. 10

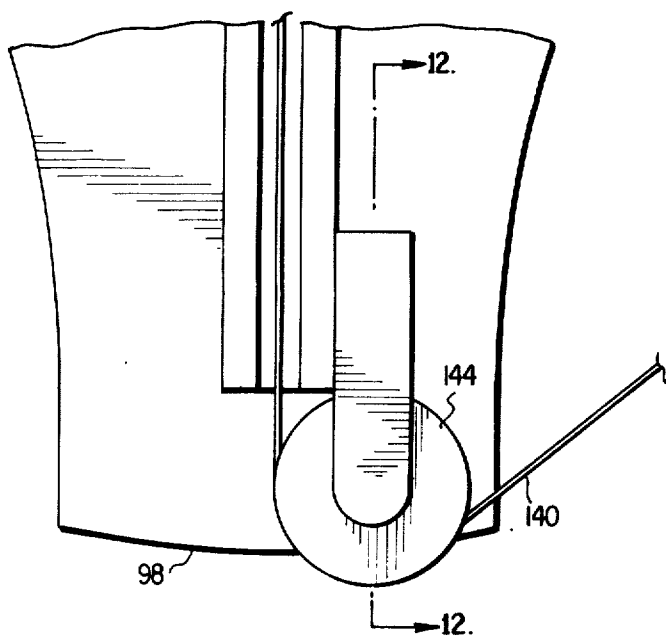


FIG. 9

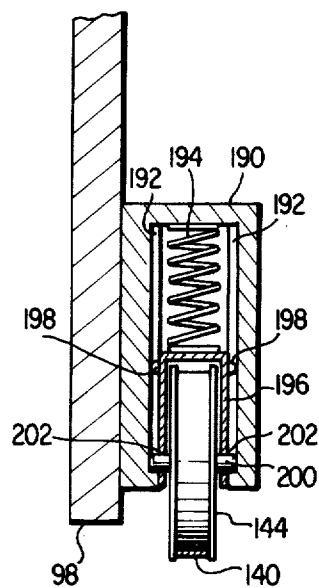


FIG. 12

ROTARY PISTON ENGINE AND PISTON PHASING APPARATUS THEREFOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to controlling the relative motion between rotary pistons of a rotary piston device, such as an internal combustion engine in which all rotary pistons move in the same general direction of rotation but have relative motion therebetween.

Description of the Prior Art

U.S. Pat. No. 3,476,056 issued to James A. Bright on Nov. 4, 1969 discloses a pump having oscillating vanes whose motion is controlled by a planetary gear system wherein the pinions are provided with an eccentric pin which engages a slot of a plate connected to one set of rotary vanes. The construction of the Bright patent, however, with its slender eccentric pins to transmit rotary motion, comprises a fragile means of creating the necessary oscillatory motion and is not well suited to internal combustion engines. Other proposals to create oscillatory motion between rotating pistons are illustrated by the patent issued to William McMahon, U.S. Pat. No. 3,730,654 on May 1, 1973, and the patent issued to Hans Schudt, U.S. Pat. No. 3,398,643 on Aug. 27, 1968. The Schudt and McMahon patents are illustrative of eccentric gearing arrangements between the shafts carrying the oscillating rotary pistons which require specially-fabricated complex gears. The gears, in addition to being noisy, must be provided with extremely close tolerances to provide reliable operation. Moreover, the eccentric gear of the Schudt patent are not well suited for devices having a high angular velocity since dynamic balancing becomes a problem.

U.S. Pat. No. 1,556,843, issued to Cloyd L. Kinder on Oct. 13, 1925, discloses a rotary piston device wherein the motion of one of the rotary piston elements is varied with respect to the constant motion of a second rotary piston element by means of a cam-slot arrangement. The cam-slot arrangement of Kinder does not, however, accommodate oscillatory motion of both piston elements. In addition, the Kinder apparatus would be exceptionally difficult to balance dynamically for high speed rotation.

U.S. Pat. No. 3,075,506, issued to Frank Berry on Jan. 29, 1963, discloses a spherical trajectory rotary power device which is provided with a three-dimensional cam groove to control the oscillatory rotary motion of piston elements therein. The cam groove of the Berry patent, however, would be exceptionally difficult to fabricate in view of its three-dimensional character.

SUMMARY OF THE INVENTION

The instant invention provides a durable, compact phasing apparatus for controlling the oscillatory motion of a pair of rotary piston elements and a rotary power shaft. The phasing apparatus is particularly well-suited for an internal combustion engine. A phasing member provided with a curvilinear internal ring gear is used to control the relative motion between rotary piston elements. Two pair of equiangularly spaced rotary pinions are provided which mesh with the internal curvilinear ring gear. The two pair of rotary pinions are constrained to move radially with respect to the axis of rotation of the rotary power shaft. Each pair of rotary pinions are interconnected with one of the rotary pis-

tons through a simple gear and shaft mechanism. The symmetrical arrangement of the rotating parts provides an assembly which is well suited for dynamic balancing.

The use of pistons which move in the same general direction but which oscillate with respect to one another, reduces the amount of otherwise useful energy which would be wasted in conventional reciprocating piston arrangements.

The phasing apparatus design allows easy modification of the compression ratio of a space defined between adjacent pistons for any suitable application.

The piston shape disclosed allows centrifugal force to assist sealing engagement between compression rings and the piston chambers.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description of a preferred embodiment of the invention makes reference to the accompanying drawings in which:

FIG. 1 is a perspective view of an internal combustion engine;

FIG. 2 is an exploded perspective view of several basic elements of the invention as they would appear in FIG. 1 with the housing removed;

FIG. 3 is a cross-sectional view taken through a generally vertical plane as illustrated by line 3—3 in FIG. 1;

FIG. 4 is a cross-sectional view taken along line 4—4 of FIG. 3;

FIGS. 5, 6, 7 and 8 are cross-sectional views taken along line 5—5 of FIG. 3;

FIGS. 5A, 6A, 7A and 8A correspond to each of FIGS. 5 through 8 and illustrate the corresponding positioning of fundamental elements of the timing mechanism;

FIG. 9 is an enlarged view of the belt tensioning mechanism which is illustrated in smaller detail in FIG. 4;

FIG. 10 is a half elevation along centerline 10—10 of FIG. 1;

FIG. 11 is partial elevation of one rotary piston; and

FIG. 12 is a cross-sectional view along line 12—12 of FIG. 9.

DETAILED DESCRIPTION OF THE INVENTION

The compact external configuration of an internal combustion engine which employs the novel phasing mechanism of this invention is illustrated in FIG. 1. In the interest of clarity, such conventional devices as carburetion, cooling systems, ignition systems, and starting mechanisms are not shown. A housing 20 is provided which includes a front cover plate 22, an intermediate housing 24, a rear housing 26 and a rear cover plate 29. Rear cover plate 29 is suitably secured to flange 28 of rear housing 26 to provide access to rotary plate 94. Flange 30 of the rear housing 26 is suitably fastened to flange 32 of intermediate housing 24 and thus allows access to phasing cavity 54. Flange 34 of intermediate housing 24 is suitably fastened to flange 36 of front cover plate 22 to allow access to piston cavity 52.

The front cover plate 22 is provided with a pipe 38 through which coolant is admitted to a cooling jacket to be described more fully hereinafter. Intermediate housing 24 is provided with a pipe 40 through which coolant is removed from the cooling jacket. The inlet and outlet may however, be reversed such that pipe 40 is the inlet and pipe 38 is the outlet.

A rotary power shaft 42 protrudes from housing 20 through rear cover plate 29. Shaft 42 may be connected to any suitable device such as a transmission (not shown) when the apparatus of the instant invention is used as an internal combustion engine. When the apparatus is used as a pump, shaft 42 is a power input; when used as a motor, shaft 42 is a power output shaft.

Inlet ports 44 are provided in front cover plate 22 to admit a combustible mixture to the internal combustion engine from a suitable carburetor (not shown). Similarly, exhaust ports 46 are provided in front cover plate 22 to permit the exhaustion of gases from the internal combustion engine. A spark plug 48 is provided in the front cover plate 22 and is connected to a suitable ignition system (not shown). The coolant inlet pipe 38 and coolant outlet pipe 40 may be connected to a suitable radiator and coolant recirculation system.

The relationship between the internal combustion engine components, the phasing mechanism, and the housing 20 is clearly shown in FIG. 3. A cooling jacket or cavity 50, 56 is provided in the housing 20 to cool the combustion chamber and to cool lubricating oil disposed within phasing cavity 54. Cooling cavity 50 provided in the front housing cover 22 and cooling cavity 56 is disposed within the intermediate housing 24. The front housing cover 22 and the intermediate housing 24 also define a piston cavity 52. Moreover, housing 20 defines a phasing cavity 54 to which access is provided through flanges 30, 32. Cooling cavities 50, 56 communicate with one another through openings 58 provided in flanges 34, 36 thereby allowing a continuous circulation of coolant to pass from pipe 38 to pipe 40.

A plurality of the exhaust ports 46, illustrated in FIG. 3, communicate with the piston cavity 52 through conduits 55 which pass through cooling cavity 50. Intake ports 44 are similarly provided with conduits 55 that communicate with piston cavity 52.

A first rotary piston element 60 and a second rotary piston element 62 are disposed within the piston cavity 52. The first rotary piston element 60 is connected to one end of an inner coaxial piston shaft 64 which is disposed within the piston cavity 52. Each rotary piston element 60, 62 is provided with a pair of piston faces to be more fully described hereinafter. The second rotary piston element 62 is attached to one end of an outer coaxial piston shaft 66 which protrudes into the piston cavity 52. The rotary piston elements 60, 62 may also be integrally connected to the respective coaxial piston shaft 64, 66. The inner coaxial piston shaft 64 and the outer coaxial piston shaft 66 may be provided with suitable bearings therebetween and between the respective shafts and housing 20. The bearings may be roller bearings or ball bearings and are considered to be a matter of design. Likewise, suitable gaskets may be provided as required. One end of the inner coaxial piston shaft 64 and one end of the outer coaxial piston shaft 66 protrude into the phasing cavity 54. The inner coaxial piston shaft is journaled, or otherwise mounted for relative motion, in the end 43 of rotary power shaft 42. The end of outer coaxial shaft 66 which protrudes into phasing cavity 54, is provided with a driving gear 70. Similarly, the inner coaxial piston shaft is provided with a driving gear 72.

The means whereby the coaxial piston shafts are interconnected will now be described in detail. This interconnection means comprises a piston phasing mechanism

which, as noted above, is suitable for any rotary piston device. For the purposes of this discussion, FIGS. 2, 3 and 4 are most helpful in visualization of the apparatus to which reference is made.

At the heart of my phasing mechanism is a phasing member 80 which is illustrated in FIG. 3 as an integral portion of rear housing 26. It should be noted, however, that the phasing member could be removably connected to the housing member 26 in any suitable fashion, for example, by being bolted thereto. The phasing member 80 is provided with a phasing opening 82 which defines a curvilinear opening that has gear teeth 83 thereon. The phasing member 80 thus defines a generally curvilinear two-dimensional internal ring gear. The phasing member 80 is provided with raised machined surfaces 84, 86 on the front and rear surfaces thereof. The function of these surfaces will be described in more detail later. As illustrated in FIG. 4, four pinions 88 are provided which mesh with the teeth 83 of phasing opening 82. Each of the four pinions 88 contacts the phasing opening 82 at a different point thereon. Each pinion 88 is securely mounted on a pinion shaft 90 which is rotatably supported by a first rotary plate 92 and a second rotary plate 94. The phasing member 80 is disposed between the first rotary plate 92 and the second rotary plate 94, in the preferred embodiment, so that the pinion shaft may be simply supported. When so desired, the first and the second rotary plates 92, 94 may be provided with arcuate cutouts 100 as illustrated in FIG. 4. The arcuate cutouts 100 of the first rotary plate 92 define a plurality of peripheral portions 98. Between each of the peripheral portions 98 of rotary plates 92, 94, and the phasing member 80, a bearing 96 is provided which coacts with machined bearing surfaces 84, 86 of the phasing member 80 to support and position the rotary plates 92, 94.

Both the first rotary plate 92 and the second rotary plate 94 are connected to the rotary power shaft 42 such that the plates and the shaft are constrained to rotate simultaneously. A spacer 95 is concentrically provided on the rotary power shaft to accurately position the first and second rotary plates 92, 94. Each rotary plate 92, 94 is provided with a plurality of radial slots 102. The radial slots 102 of the first rotary plate 92 and the slot 102 of the second rotary plate 94 are axially aligned. Each radial slot 102, receives one end of a pinion shaft 90 which is rotatably mounted in a carriage means 104 that slides longitudinally of the radial slot. The radial orientation of the slots 102 constrains each pinion 88 and associated pinion shaft 90 to move in a radial direction only.

It will be noted that the gears to be described are illustrated on the Figures as conventional offset bevel gears which permit power transmission between non-intersecting shafts. A modification to be described hereinafter may use conventional bevel gears.

The driving gear 70 attached to the outer coaxial piston shaft 66 meshes with a first fixed driven gear 110 which is attached approximately at the center of a first splined shaft 112. Splined shaft 112 is perpendicularly aligned with respect to the axis of the coaxial piston shafts 64, 66. The first splined shaft 112 is rotatably supported by shaft mountings 113 disposed at each end thereof. The shaft mountings 113 are suitably mounted on the first rotating plate 92. A first translating gear 114 is disposed between the fixed driven gear 110 and one end of shaft 112. The translating gear 114 is pro-

vided with a splined bore which permits the translating gear 114 to slide longitudinally along splined shaft 112. Shaft 112 drives the first translating gear 114 in accordance with the rotary motion imparted to shaft 112 from coaxial piston shaft 66 through the gears 70, 110. A second translating gear 116 is disposed between the fixed driven gear 110 and the second end of splined shaft 112 and is similarly driven thereby. The first translating gear meshes with a first pinion driving gear 118 which is attached to one end of one pinion shaft 90. A second pinion driving gear 120 meshes with the second translating gear 116 and is attached to another pinion shaft 90. To maintain meshed engagement between the first translating gear 114 and the first pinion driving gear 118, an L-shaped member 122 is provided. The L-shaped member 122 constrains the meshed gears 114, 118 to be constantly in mesh while permitting relative rotation between each gear 114, 118 and the L-shaped member 122. A similar L-shaped member 122 is provided for the second translating gear 116 and the second pinion driving gear 120 which meshes therewith.

Analogously, the inner coaxial shaft 64 drives the driving gear 72 which meshes with a second fixed driven gear 124 carried by a second splined shaft 126. The second splined shaft 126 is rotatably mounted on shaft mountings 128 each of which is suitably secured to the first rotating plate 92. The second splined shaft 126 is perpendicular to the inner coaxial shaft 64 and is also perpendicular to the first splined shaft 112. The first splined shaft 112 and the second splined shaft 126 are not, however, coplanar as may clearly be seen from FIGS. 2 and 3. A third translating gear 120 is slidably mounted on splined shaft 126 in a manner similar to that whereby the first translating gear 114 is mounted on first splined shaft 112. Similarly, a fourth translating gear 132 is slidably mounted on shaft 126 in the same fashion that translating gear 116 is mounted on shaft 112. The third translating gear 130 meshes with a third pinion driving gear 134 carried by a pinion shaft 90; the fourth translating gear 132 meshes with a fourth pinion driving gear 136 carried by the remaining pinion shaft 90. An L-shaped member 122 maintains meshed engagement between gears 130, 134 and another L-shaped member 122 maintains engagement between gears 132, 136.

A first gear ratio R_1 is defined by the number of teeth on a fixed driven gear (110 or 124) divided by the number of teeth on a fixed driving gear (70 or 72). A second gear ratio R_2 is defined by the number of teeth on a pinion driving gear (118, 120, 134, or 136) divided by the number of teeth on a translating gear (114, 116, 130, or 132). A third gear ratio, R_3 , is defined by the number of teeth on the internal ring gear (82) divided by the number of teeth on a pinion 88. The product of the first and second gear ratios must equal the third gear ratio, i.e. $R_3 = R_1 \times R_2$, so that each pinion will make one complete traversal of phasing opening 82 for each complete revolution of rotary piston elements 60, 62.

To ensure meshed engagement between the pinions 88 and the teeth 83 of phasing opening 82, a first tensioning band 140 and a second tensioning band 142 are provided. One end of each tensioning band is secured to one pinion shaft 90 between the pinion driving gear thereon and the first rotating plate 92 by any suitable means. First tensioning band 140 interconnects two

pinions 88 in adjacent radial slots 102 which pinions are driven by pinion driving gears 120 and 134. Second tensioning band 142 interconnects two pinions 88 which are driven by pinion driving gears 118 and 136. At each peripheral portion 98 of the first rotary plate 92, a spring-biased tensioning pulley 144 is provided, typically as illustrated in FIG. 4 by reference 143.

FIG. 9 illustrates one of the many devices whereby tensioning pulleys 144 may be mounted on rotary plate 92. A pulley support 190 has a C-shaped configuration and is provided with two longitudinal slots 192. Pulley 144 is mounted on a pulley shaft 200 that is supported in holes 202 of a pulley cage 196. The ends of pulley shaft 200 protrude through pulley cage 196 and are received within longitudinal slots 192. Pulley cage 196 is provided with a pair of pins 198 which are likewise received by longitudinal slots 192. Biasing spring 194 resiliently urges the pulley cage 196 and the pulley 144 carried thereby toward the peripheral portion 98 of the rotary member 92. The pins 198 and the protruding ends of pulley shaft 200 engage the longitudinal slots 192 and guide the translatory motion of the pulley 144.

A dynamic balancing means 146 may be disposed at the peripheral portions 98 of the first rotating plate 92 to accommodate rotational imbalance due to the placement of the non-coplanar splined shafts 112, 126. The detail of the balancing means is a matter of design which is not relevant of the disclosure of this invention.

Each rotary piston element 60, 62 includes a pair of diametrically opposed piston faces 150, 152 and 154, 156, respectively. Depending from each of the diametrically opposed piston faces 150, 153, 154, 156 is a segmentally shaped skirt 158 which is shown most clearly in FIGS. 2 and 5. The planform of each piston face 150, 152, 154, 156 includes a pair of straight converging sides 160, 162 which are tangent to a generally circular portion 164 at the radially outermost portion thereof. The piston cavity 52 is circular when viewed along the line 5-5 of FIG. 3 and the cross section thereof is similar to the planform of the piston faces 150, 152, 154, 156.

Compression rings 161 are retained in ring grooves 160 provided on skirt 158 depending from each piston face 150, 152, 154, 156 as typically shown in FIG. 11. The convergent sides 160, 162 of each piston face 150, 152, 154, 156 allow centrifugal force, resulting from rotary motion of rotary pistons 60, 62, to assist sealing engagement between compression rings 161 and piston cavity walls 159.

Lubrication of the phasing apparatus here disclosed may be done in any conventional manner. One method is to provide an oil bath in phasing cavity 54. To provide a uniform oil level on both sides of phasing member 80, an oil passage opening 162 may be used as shown in FIG. 3. Of course, other methods such as an oil spray are also possible.

The operation of the phasing apparatus of this invention in combination with an internal combustion engine, will now be described by reference to FIGS. 5, 5A, 6, 6A, 7, 7A, 8 and 8A.

Arrow 160 on FIG. 5 indicates the direction of rotation of both rotary pistons 60, 62 within piston cavity 52. As noted, rotary piston 60 is provided with a pair of diametrically opposed piston faces 150, 152. Similarly, rotary piston element 62 is provided with a pair of diametrically opposed piston faces 154, 156. A first working chamber 170 is defined between adjacent pis-

ton faces 150 and 154 of rotary pistons 60, 62. Similarly, a second working chamber 175 is defined between adjacent piston faces 152, 156 of rotary pistons 60, 62. As shown in FIG. 5, the working chamber 170 contains a combustible mixture in a maximum state of compression.

The positioning of two pinions 88A, 88B and their relationship to the phasing opening 82 of phasing member 80, which corresponds to the position of rotary pistons 60, 62 in FIG. 5, as illustrated by FIG. 5A. Pinion 88A is connected with piston faces 150, 152 of rotary piston 60 which is attached to the inner coaxial shaft piston 64. Rotary motion is imparted to the pinion 88A through the gearing arrangement discussed above in connection with the inner coaxial piston shaft 64. Similarly, pinion 88B is connected with rotary piston 62 that is connected with the outer coaxial piston shaft 66. The gearing arrangement discussed above in connection with outer coaxial piston shaft 66 causes rotary motion of pinion 88B in relation to the phasing opening 82. Angle *a*, illustrated in FIG. 5A corresponds to the angle between adjacent radial slots 102 provided on the first rotary plate 92. Accordingly, angle *a* remains constant as pinions 88A, 88B traverse the phasing opening 82. Angle *b*, represents the contact angle between pinions 88A, 88B and the phasing opening. As will be apparent from an examination of FIGS. 5A, 6A, 7A and 8A, the contact angle *b* varies as the pinions 88A, 88B traverse phasing opening 82.

Spark plug 48 is positioned such that it communicates with working chambers 170, 175 when a working chamber has compressed a combustible mixture to the maximum extent permitted by the configuration of phasing opening 82. The spark plug 48 would be positioned in communication with first working chamber 170, as shown in FIG. 5. Spark plug 48 ignites the compressed combustible mixture in the first working chamber 170 thereby exerting a high pressure on piston faces 150, 154 and causing a power stroke. As will be noted from a comparison of FIGS. 5A and 6A, pinion 88A must traverse a greater arc length of phasing opening 82 than does pinion 88B when the rotary plates 92, 94 rotate through an angle of 90°. Since each pinion is interconnected with a piston face, piston face 150 will rotate at a more rapid rate and with increasing mechanical advantage within piston cavity 52 than will piston face 154 in response to the power stroke generated by the detonation of combustible mixture in working chamber 170. Working chamber 170 is shown in FIG. 6 at the end of the power stroke.

Exhaust ports 46 are positioned in the housing front cover plate 22 in the arcuate area 180 illustrated in FIGS. 5 through 8 and 10. Similarly, intake ports 44 are positioned on the housing front cover plate 22 along the arcuate area 185 which is also illustrated in FIGS. 5 through 8 and 10. Depending upon the operating conditions selected for the engine, it may be desirable to provide valving for some or all of the inlet ports 44 or exhaust port 46 or both. Such valving would be part of the carburetion system and is thus not shown.

The actual placement and sizing of the ports 44, 46 will determine whether the rotary pistons will function to compress or expand fluid which enters the working chambers 170, 175. Accordingly, when the phasing apparatus is used in a pump or motor, the arcuate positioning of ports 44, 46 may require modification.

The exhaustion of spent combustion products from working chamber 170 occurs as piston face 150 moves into the arcuate area 180. It will be noted from a comparison of FIGS. 6A and 7A that pinion 88B now must traverse a longer arc length of phasing opening 82 than does pinion 88A. Accordingly, piston face 154 will approach piston face 150 thereby contracting the first working chamber 270 and assisting the exhaust of combustion products therefrom. The working chamber 270 in its fully exhausted condition immediately prior to the intake of a fresh charge of combustible mixture is shown in FIG. 7. Thus, FIG. 7 illustrates the piston positions at the end of an exhaust stroke.

From a comparison of FIGS. 7A and 8A, it will be seen that pinion 88A must now increase its rate of rotation relative to the rotation of pinion 88B in order to traverse the greater arc length between pinion positions shown in FIGS. 7A and 8A. Accordingly, piston face 150 will move away from piston face 154 and expand working chamber 170. In so doing, piston face 150 moves into the arcuate area 185 where inlet ports 44 are located. The expansion of the first working chamber 170 between piston faces 150 and 154 creates a low pressure region which sucks in a fresh charge of combustible mixture thereby causing an intake stroke. The intake of a new charge of a combustible mixture continues until trailing piston face 154 moves out of the arcuate inlet area and thus interrupts fluid communication between the inlet ports 44 and the first working chamber 170.

By comparing FIGS. 8A and 5A, it will be seen that the first working chamber 170 is compressed by the relative motion between piston faces 150 and 154 whose motion is determined by the rate of revolution of pinions 88A and 88B over the respective arc lengths of phasing opening 82. The compression corresponds to a compression stroke of a four cycle engine.

A second working chamber 175 defined between piston faces 152 and 156 goes through the same intake, compression, power and exhaust strokes as does the first working chamber 170. The second working chamber 175 however, is 180° out of phase with the first working chamber 170 in the sequence of strokes. Thus it is apparent that each revolution of power shaft 42 is accompanied by two power strokes of the internal combustion engine.

It should be noted that the arcuate inlet area 185 and arcuate exhaust area 180 may be varied to control the length of time that the working chambers 170, 175 communicate with the intake ports 44 and exhaust ports 46. By providing the arcuate exhaust area 180 in a relatively small angle, the residence time of combustion products within a working chamber after the detonation thereof by the spark plug 48 may be substantially increased. Such an increase in residence time is effective to enhance complete combustion of the combustible mixture and thereby diminish the polluting effect of exhaust products from the engine.

In addition, by injecting fuel directly into working chambers 170, 175 near the point of maximum compression, the phasing apparatus could control a diesel engine cycle.

At this point, it should be abundantly clear to one skilled in the art that the shape of the phasing opening 82 makes possible the simple and durable operation of my invention. In addition, it is clear that phasing opening 82 may not be a circular opening, since a circular

opening would not cause the different angular velocities of a pair of pinions **88A**, **88B** which is necessary to create relative motion between rotary pistons **60**, **62**. However, it will be apparent to those skilled in the art that an elliptical opening may be used for the phasing opening **82** to create relative motion between piston elements **60**, **62**. The bar bell shape which is illustrated for the phasing opening **82** is merely one variation of the phasing opening **82** which may be used. The bar bell shape however, provides the maximum compression ratio for the working chambers **170**, **175**. The compression ratio may be increased by either extending the length of phasing opening **82** or by decreasing the width of the phasing opening **82**. Naturally, the width of phasing opening **82** can be decreased only to the point where it is wide enough to allow pinions **88** to pass between rotary power shaft **42** and the adjacent phasing opening **82**.

When used as an internal combustion engine, the useful work developed by the variable working chambers **170**, **175** is imparted to the rotary power shaft **42** by the variable length lever arm defined between the axis of piston shaft rotation and the axis of pinion shafts **90**.

Other mechanical arrangements to interconnect the coaxial piston shafts **64**, **66** and the rotary plates **92**, **94** may be devised without departing from the scope of my invention. For example, instead of using the offset bevel gears as illustrated in the drawings, worm and worm wheel combinations could be used to transmit the necessary rotary motion between the coaxial shafts **64**, **66** and the pinions **88**.

In addition, instead of using a single off-set splined shaft, a pair of shorter splined shafts may be used which are coaxially disposed with the appropriate driving gear **70** or **72**. In this case each shorter splined shaft would be provided with a fixed gear to mesh with the driving gear **70**, **72** of one of the coaxial piston shafts. Simple bevel gears may be then used since the driving and driven shafts could be coplanar. The embodiment illustrated in the drawings, however, is the preferred embodiment.

One advantage of this invention is the placement of the cooling cavity **56** between the piston cavity **52** and the phasing cavity **54**. The phasing cavity **54** is provided with lubricating oil which is thus cooled by the liquid provided in cooling cavity **56**.

A further advantage of my invention is that centrifugal force caused by the rotation of rotary plates **92**, **94** acts on the pinions **88** to assist their engagement with the phasing opening **82**.

Dynamic balancing of the apparatus may be quickly and efficiently accomplished in view of the placement of balancing means herein described.

The advantage of a smooth, continuous rotary power output is made possible by the oscillatory motion of both rotary pistons. Since both pistons have a basic rotary motion in the same direction, energy which might otherwise be lost in pure reciprocating motion is substantially reduced.

Moreover, the disclosed apparatus is simple yet durable. The parts required are either readily available off-the-shelf items or are parts which may be inexpensively produced.

Positioning of inlet and outlet ports advantageously allows control of combustion product residence time

within the working chamber. This control can be used to substantially reduce atmospheric pollutants.

Shaping of the combustion chamber and rotary piston faces advantageously allows centrifugal force acting on compression rings to assist the sealing function of those rings.

In addition, the positioning of the phasing apparatus adjacent to the piston cavity with a portion of the cooling jacket therebetween gives an added advantage in that lubricating oil in the phasing cavity can be cooled simultaneously with the piston cavity.

While the detailed description above describes a preferred embodiment of this invention, it is not meant to be limitation of the scope of the invention which is given by the claims appended hereto. Accordingly, this invention is defined by the claims, and all modifications and equivalents of the claims are expressly intended to be within the scope of the invention.

What is claimed is:

1. A phasing mechanism for a pair of rotary pistons comprising:

a pair of coaxial piston shafts, each of said piston shafts connected to one of said pair of rotary pistons;

a rotary power shaft coaxially aligned with said pair of coaxial piston shafts;

a phasing member provided with a phasing opening, said phasing member coaxially disposed about said rotary power shaft, said phasing opening having a predetermined shape which determines relative motion of said pair of rotary pistons;

at least one pair of rotary members each being constrained to move radially with respect to the axis of said rotary power shaft, each said rotary member engaging said phasing opening at a location spatially separated from the location at which the other of said at least one pair of rotary members engages said phasing opening;

at least one tensioned band having one end carried by one of said pair of rotary members and the other end carried by the second of said pair of rotary members and being operable to resiliently urge said pair of rotary members radially outwardly into engagement with said phasing opening; and,

means for interconnecting said pair of coaxial piston shafts and said rotary power shaft, said interconnecting means carrying said at least one pair of rotary members, said interconnecting means permitting relative motion between said coaxial piston shafts and also permitting relative motion between said coaxial piston shafts and said rotary power shaft.

2. The phasing mechanism of claim 1 wherein: said phasing member comprises a curvilinear internal ring gear.

3. The phasing mechanism of claim 1 wherein: said interconnecting means includes a pair of rotary plates disposed adjacent said phasing member and connected to said rotary power shaft, each of said rotary plates provided a radial slot for each of said at least one pair of rotary members.

4. The phasing mechanism of claim 1 wherein: said interconnecting means includes a pair of rotary plates, each plate provided with at least one pair of perpendicular radial slots, said radial slots of one said plate being aligned with said radial slots of the

other said plate, said rotary plates connected to said rotary shaft;

said phasing member comprises a curvilinear internal ring gear disposed adjacent said pair of rotary plates;

said at least one pair of rotary members being pinions which mesh with said curvilinear internal ring gear, each of said at least one pair of pinions constrained to move radially with respect to said pair of rotary plates, each of said at least one pair of perpendicular radial slots of said pair of rotary plates; and

said interconnecting means including means for correlating the rotation of said at least one pair of pinions and said pair of coaxial piston shafts such that said rotary plates make one full revolution for each full revolution of said pair of coaxial piston shafts.

5. The phasing mechanism of claim 4 wherein: each of said pair of rotary plates includes two pairs of symmetrically disposed perpendicularly aligned slots; and

two pairs of rotating pinions are provided, each pinion being carried by one of said perpendicularly aligned radial slots.

6. The phasing mechanism of claim 4 wherein: said curvilinear internal ring gear defines a generally barbell-shaped opening.

7. A rotary power device comprising:

a housing which defines a phasing cavity and a piston cavity;

a pair of rotary piston elements mounted within said piston cavity;

a pair of coaxial piston shafts, one end of each said pair of coaxial piston shafts connected to one of said rotary piston elements;

a rotary power shaft coaxially aligned with said pair of coaxial piston shafts and having one end disposed within said phasing cavity;

a phasing member provided with a phasing opening, said phasing member coaxially disposed about said rotary power shaft within said phasing cavity, said phasing opening having a predetermined shape which determines relative motion of said pair of rotary piston elements;

at least one pair of rotary members each being constrained to move radially with respect to the axis of said rotary power shaft, each said rotary member engaging said phasing opening at a location spatially separated from the location at which the other of said at least one pair of rotary members engages said phasing opening;

at least one tensioned band having one end carried by one of said pair of rotary members and the other end carried by the second of said pair of rotary members and being operable to resiliently urge said pair of rotary members radially outwardly into engagement with said phasing opening; and,

means for interconnecting said pair of coaxial piston shafts and said rotary power shaft, said interconnecting means carrying said at least one pair of rotary members, said interconnecting means permitting relative motion between said coaxial piston shafts and also permitting relative motion between said coaxial piston shafts and said rotary power shaft.

8. The rotary power device of claim 7 wherein: said interconnecting means includes a pair of rotary plates each of which is provided with at least one

pair of perpendicularly aligned radial slots, each of said rotary plates being attached to said rotary power shaft and said at least one pair of perpendicular radial slots of one rotary plate being aligned with said at least one pair of perpendicular radial slots of the second of said rotary plates;

said phasing member comprises a curvilinear internal ring gear connected to said housing and disposed adjacent to said rotary plates;

said at least one pair of rotary members are pinions which mesh with said internal curvilinear ring gear; and,

said interconnecting means constrains said rotary plates to make one complete revolution for each complete revolution of said pair of coaxial piston shafts.

9. The rotary power device of claim 8 wherein: the cross-section of each said piston element includes a pair of straight converging sides which are tangent to a generally circular end portion; and said piston cavity is provided with a cross-section similar to the shape of said piston elements.

10. The rotary power device of claim 8 wherein: said housing also defines a cooling jacket which surrounds said piston cavity, said cooling jacket being disposed partially between said phasing cavity and said piston cavity.

11. A phasing mechanism for a pair of rotary pistons comprising:

a pair of coaxial piston shafts, each of said piston shafts connected to one of said pair of rotary pistons;

a rotary power shaft coaxially aligned with said pair of coaxial piston shafts;

a phasing member provided with a phasing opening, said phasing member coaxially disposed about said rotary power shaft, said phasing opening having a predetermined shape which determines relative motion of said pair of rotary pistons;

at least one pair of rotary members each being constrained to move radially with respect to the axis of said rotary power shaft, each said rotary member engaging said phasing opening at a location spatially separated from the location at which the other of said at least one pair of rotary members engages said phasing opening;

means for interconnecting said pair of coaxial piston shafts and said rotary power shaft, said interconnecting means carrying said at least one pair of rotary members, said interconnecting means permitting relative motion between said coaxial piston shafts and also permitting relative motion between said coaxial piston shafts and said rotary power shaft;

said interconnecting means includes a pair of rotary plates, each plate provided with at least one pair of perpendicular radial slots, said radial slots of one said plate being aligned with said radial slots of the other said plate, said rotary plates connected to said rotary shaft;

said phasing member comprises a curvilinear internal ring gear disposed adjacent said pair of rotary plates;

said at least one pair of rotary members being pinions which mesh with said curvilinear internal ring gear, each of said at least one pair of pinions constrained to move radially with respect to said pair of rotary

plates, each of said at least one pair of pinions carried by one of said at least one pair of perpendicular radial slots of said pair of rotary plates;

said interconnecting means including means for correlating the rotation of said at least one pair of pinions and said pair of coaxial piston shafts such that said rotary plates make one full revolution for each full revolution of said pair of coaxial piston shafts;

said phasing mechanism includes means for maintaining engagement between said at least one pair of pinions and said curvilinear internal ring gear; and,

said means for maintaining engagement includes a tensioned steel band, one end of which is attached to one of said at least one pair of pinions the other end of which is attached to the second of said at least one pair of pinions.

12. The phasing mechanism of claim 11 wherein:

said means of maintaining engagement includes a radially movable pulley disposed at the radially outermost end of each of said at least one pair of perpendicularly aligned radial slots; and

biasing means urging each of said pulleys radially outward whereby said steel band is maintained in a tensioned condition.

13. A phasing mechanism wherein:

a pair of coaxial piston shafts, each of said piston shafts connected to one of said pair of rotary pistons; a rotary power shaft coaxially aligned with said pair of coaxial piston shafts;

a phasing member provided with a phasing opening, said phasing member coaxially disposed about said rotary power shaft, said phasing opening having a predetermined shape which determines relative motion of said pair of rotary pistons;

at least one pair of rotary members each being constrained to move radially with respect to the axis of said rotary power shaft, each said rotary member engaging said phasing opening at a location spatially separated from the location at which the other of said at least one pair of rotary members engages said phasing opening;

means for interconnecting said pair of coaxial piston shafts and said rotary power shaft, said interconnecting means carrying said at least one pair of rotary members, said interconnecting means permitting relative motion between said coaxial piston shafts and also permitting relative motion between said coaxial piston shafts and said rotary power shaft;

said interconnecting means includes a pair of rotary plates, each plate provided with at least one pair of perpendicular radial slots, said radial slots of one said plate being aligned with said radial slots of the other said plate, said rotary plates connected to said rotary shaft;

said phasing member comprises a curvilinear internal ring gear disposed adjacent said pair of rotary plates;

said at least one pair of rotary members being pinions which mesh with said curvilinear internal ring gear, each of said at least one pair of pinions constrained to move radially with respect to said pair of rotary plates, each of said at least one pair of pinions carried by one of said at least one pair of perpendicular radial slots of said pair of rotary plates;

said interconnecting means including means for correlating the rotation of said at least one pair of pinions and said pair of coaxial piston shafts such that said rotary plates make one full revolution for each full revolution of said pair of coaxial piston shafts;

said phasing mechanism includes means for maintaining engagement between said at least one pair of pinions and said curvilinear internal ring gear;

said means for correlating the rotation of said pinions and said pair of coaxial piston shafts includes a pair of driving gears, one of said driving gears connected to one of said pair of coaxial piston shafts, the other said driving gear being connected to the other of said coaxial piston shafts;

at least one pair of perpendicular rotary shafts, each of which is rotatably mounted on one of said rotating plates;

a pair of fixed gears, each of which is mounted on one of said at least one pair of perpendicular rotary shafts approximately midway between the ends thereof;

at least one pair of translating gears, each of which is mounted on one of said at least one pair of perpendicular rotary shafts between said fixed gear and an end of said perpendicular rotary shaft such that each perpendicular rotary shaft has one translating gear thereon;

a pair of pinion driving gears, each pinion driving gear connected with one of said at least one pair of pinions and meshing with one of said translating gears; and

means constraining each said translating gear to slide radially with respect to said rotary member, each said constraining means being connected to one of said at least one pair of pinions.

14. An internal combustion engine comprising:

a. a housing which defines a generally circular cavity, a phasing cavity and a cooling jacket which is partially interposed between said phasing cavity and said generally circular cavity,

a first and a second rotary piston element each disposed within said generally circular cavity;

b. each said rotary piston element comprising:

two diametrically opposed piston faces,

each said piston face having a pair of straight converging sides and a generally curved end,

a segment shaped skirt defining two radial edges depending from each said piston face, and

compression rings provided on each said radial edge of said skirt;

c. an inner coaxial piston shaft attached at one end to said first rotary piston element;

d. an outer coaxial piston shaft attached at one end to said second rotary piston element and coaxially disposed about said inner coaxial piston shaft;

e. a first driving bevel gear attached near the second end of said inner coaxial piston shaft and disposed within said phasing cavity;

f. a second driving bevel gear attached to the second end of said outer coaxial piston shaft and disposed within said phasing cavity;

g. a first splined shaft disposed within said phasing cavity and generally perpendicularly arranged with respect to said inner coaxial piston shaft;

h. a first fixed bevel gear disposed approximately midway between the ends of said first splined shaft, said first fixed bevel gear meshing with said first

- driving bevel gear attached to said inner coaxial piston shaft;
- i. a second splined shaft disposed within said phasing cavity and perpendicularly arranged with respect to said outer coaxial piston shaft; 5
 - j. a second fixed bevel gear disposed approximately midway between the ends of said second splined shaft, said second fixed bevel gear meshing with said second bevel gear attached to said outer coaxial piston shaft; 10
 - k. a first rotary plate disposed within said phasing cavity and adapted to rotatably support said first splined shaft and said second splined shaft, said first rotary plate being provided with four radially aligned perpendicular slots; 15
 - l. a curvilinear internal ring gear disposed within said phasing cavity;
 - m. a second rotary plate provided with four radial perpendicular slots and disposed within said phasing cavity such that said curvilinear internal ring gear is between said first rotary plate and said second rotary plate, said radial slots of said first rotary plate and said radial slots of said second rotary plate being aligned with each other; 20
 - n. a rotary power shaft, one end of which protrudes from said housing, the other end of which is attached to both said first and second rotary plates; 25
 - o. four pinions, each of which meshes with the curvilinear internal ring gear;
 - p. four pinion shafts, one of said pinions being mounted on each of said pinion shafts, one end of said pinion shaft engaging one of said radial slots in said first rotary plate and the second end of said pinion shaft extending through the aligned radial slot of second rotary plate; 30
 - q. carriage means provided in each radial slot of said first and second rotary plates for engaging said pinion shaft extending therethrough and for constraining said pinion shaft to move in a radial direction within said slot; 35
 - r. a pinion bevel gear provided on the first end of 40

- each of said four pinion shafts;
- s. a first translating bevel gear which is slidably mounted on said first splined shaft between said first fixed bevel gear and one end of said first splined shaft, said first translating bevel gear meshing with the first said pinion bevel gear;
 - t. a second translating bevel gear which is slidably mounted on said first splined shaft between said first fixed bevel gear and a second end of said first splined shaft, said second translating gear meshing with the second said pinion bevel gear;
 - u. a third translating bevel gear which is slidably mounted on said second splined shaft between said second fixed bevel gear and one end of said second splined shaft, said third translating gear meshing with the third said pinion bevel gear;
 - v. a fourth translating bevel gear which is slidably mounted on said second splined shaft between said second fixed bevel gear and the other end of said second splined shaft, said fourth translating gear meshing with the fourth said pinion bevel gear;
 - w. a band pulley positioned at the radially outermost end of each said radial slots of said first rotary plate;
 - x. a first tensioning band being attached at one end to the first pinion shaft and attached at the other end to the second pinion shaft and passing over two said band pulleys each disposed at the end of two adjacent perpendicular radial slots;
 - y. a second tensioning band attached at one end to the third pinion shaft and attached at the other end to the fourth pinion shaft and passing over the two other said band pulleys each disposed at the end of the two remaining adjacent perpendicular slots; and
 - z. pulley tensioning means disposed radially inwardly of each said band pulley for tensioning each said tensioning band when said pinions traverse the curvilinear internal ring gear. 45

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