A rotary combustion engine has a rotor rotatably mounted within a cavity. The rotor has a plurality of apex portions. The profiles of the rotor and the peripheral wall of the cavity, taken together, define a plurality of working chambers. In addition, the rotary engine has means for sealing the apex portions with the peripheral wall which includes a seal strip carried by the rotor and sealingly sweeping the peripheral wall, the seal strip being radially movable relative to the rotor for maintaining sealing contact with the peripheral wall. Means are provided for reducing the contact pressure of the seal-forming means. The pressure-reducing means includes at least one lever which extends within the rotor in a direction parallel to the rotor axis and in radial alignment with its associated apex portion. The lever arm is pivotally mounted and weighted at one end. The weighted end responds to forces acting substantially in a radial direction with respect to the axis of rotation of the rotor. The lever arm is capable of applying, in at least one direction, a force to the seal-forming means tending to move the seal-forming means inwardly with respect to the rotor so as to reduce the sealing contact force against the peripheral wall.

**BRIEF DESCRIPTION OF THE DRAWING**

FIG. 1 is a sectional view of a rotary engine of FIG. 2 taken along the line 1—1 and looking in the direction of the arrows;

FIG. 2 is a sectional view of the engine of FIG. 1 taken along line 2—2 and looking in the direction of the arrows;

FIGS. 3 and 4 are schematic representations of a body tracing an epitrochoidal path; and

FIG. 5 shows an enlarged sectional view of the apex portion of the rotor of FIG. 2.

**DESCRIPTION OF THE PREFERRED EMBODIMENT**

The invention is illustrated and described in connection with a particular type of rotary internal combustion engine. It will be obvious, however, that the invention is also applicable to other rotary mechanisms and to rotary mechanisms for use as fluid pumps and fluid motors.

Refraining first to FIGS. 1 and 2 of the drawing, a rotary internal combustion engine is schematically indicated by the reference numeral 10. The engine 10 comprises an outer body 12 having axially spaced end walls 14 and 16 and a peripheral wall 18 connected therewith and forming a cavity 20. As viewed in a plane transverse to the axis 22 of the cavity 20, the multi-lobed inner profile of the wall 18 in the preferred form, is basically an epitrochoid. As illustrated herein, the cavity profile has two lobes. However, as will appear, the invention is not limited to a rotary engine having this specific arrangement.

An inner body 24 is disposed within the cavity 20 of the outer body 12. The rotor 24 has axially spaced end faces 26 and 28 disposed adjacent to and in sealing cooperation with the end walls 14 and 16. In addition, the rotor 24 has a plurality of circumferentially spaced apex portions 30 which preferably are one more in number than the number of lobes of the cavity 20. Thus, as illustrated, the cavity 20 has two lobes and rotor 24 has three apex portions 30. The outer periphery of the rotor 24 has a generally triangular profile. The apex portions 30 are in sealing engagement with the inner surface of the peripheral wall 18 to form a plurality of working chambers 32 (three are shown) between the rotor 24 and the outer body 12.

Each working chamber 32 includes a trough or channel 34 in the adjacent peripheral or working face of the rotor 24, for transfer of gases across the cusp of the epitrochoid. The geometrical axis 36 of the rotor 24 is offset from and is disposed parallel to the cavity axis 22.
In the engine 10 illustrated, the outer body 12 is stationary while the rotor 24 is journaled on an eccentric portion 38 of a shaft 40. The axis of the shaft 40 is coaxial with the cavity axis 22. (The cavity axis 22 is hereinafter referred to as the shaft axis.) Upon rotation of the rotor 24, relative to the outer body 12, the working chambers 32 vary in volume. An intake port 42 is provided in the peripheral wall 18 for admitting air and fuel into the working chambers 32; the intake port may also be located in one or both side walls. A spark plug 44 is provided for igniting the combustion mixture. An exhaust port 46 is provided in the peripheral wall 18 (or side walls) for discharge of exhaust gases from the working chambers 32. As shown, the rotor 24 turns clockwise in the direction of the arrow 66. The working chambers 32 have a cycle of operation including the four phases of intake, compression, expansion, and exhaust. The phases are similar to the four-stroke cycle of a reciprocating-type internal combustion engine. It is again emphasized that, although the preferred embodiment disclosed herein is an epichordal rotary engine, the invention is not limited to this specific type of rotary mechanism.

In order to maintain the position of the rotor 24 relative to the outer body 12, an internal ring gear 48 is coaxially secured to the rotor 24. The ring gear 48 is disposed in meshing engagement with a fixed pinion gear 50 on the end wall 16. The pinion gear 50 is coaxial with the shaft 40. In the embodiment illustrated, the meshed pinion and ring gears 48 and 50, respectively, have a gear ratio of 2 to 3.

For efficient operation, the working chambers 32 should be sealed. For this purpose a groove or slot 52 extends radially inwardly from each apex of the rotor 24 and runs from one end face 26 to the other end face 28, parallel to the rotor axis 36. An apex seal 54 is in each groove 52 and is in sealing engagement with the inner surface of the peripheral wall 18. As illustrated, each apex seal 54 comprises a single strip of metal which extends to both end walls 14 and 16 and is in sealing engagement with the peripheral and end walls 18, 14, and 16, respectively. The invention, as disclosed herein, is not limited to this particular type of apex seal structure and may be applied to variations thereof. One such structure is shown in the preceding application Ser. No. 275,481, filed July 21, 1966.

Each apex slot 52 has a cylindrically enlarged portion at each end disposed radially inwardly of its outer edge. Within the enlarged portions are apex seal pins 56 (shown in FIG. 1). Each apex seal pin 56 has a slot in register with rotor slot 52 for receiving the radially inner edge of the adjacent end of an apex seal 54.

Each rotor end face 26 and 28 has a plurality of end face seal strips 57 (shown in FIG. 2). Each of these seal strips 57 extends between a pair of adjacent seal pins 56 and cooperates with the apex seal pins 56 to provide a continuous gas seal between the end faces 26 and 28 and the end wall 14 or 16, adjacent thereto. Also, each end face 26 and 28 preferably has an oil seal ring 58 (shown in FIG. 2) disposed adjacent to its inner periphery.

The apex seals 54, the apex seal pins 56, and the end face seal strips 57 cooperate to form a continuous seal around each working chamber 32 between the rotor 24 and the outer body 12.

The apex seals 54 are not rigidly retained within the rotor 24. Instead each apex seal 54 is radially movable into and out of its slot 52 in order to maintain contact with the peripheral wall 18 notwithstanding the presence of bearing clearance, thermal distortions, and other inaccuracies. In addition, the seal slot 52 is slightly wider than the seal to permit lateral freedom of the seal. A suitable spring 60 may be provided in the slot under each apex seal 54 for urging it radially outwardly to insure contact with the peripheral wall 18.

The multi-lobed inner surface of the peripheral wall 18 has circumferentially-spaced concave portions or lobes 62 interconnected by circumferentially-spaced convex surface portions 64. As an apex seal 54 moves along a concave surface portion 62, it tends to move outwardly into contact with the peripheral wall 18. When, however, the apex seal 54 moves along a convex surface portion 64, it tends to move inwardly out of contact with the peripheral wall 18. This tendency to change the direction of the radial movement is a result of changes in the direction of the centripetal and centrifugal forces acting on these apex seals 54. These seal forces are generated as a result of the rotational path each apex seal 54 is forced to travel as a result of being confined in a slot 52 at a rotor apex portion 30. Hence, each apex seal 54 is forced to travel along the epichordal path substantially defined by the peripheral wall 18 subject, however, to limited radial movement as permitted within its apex slot 52.

To more clearly described the nature of the radial forces acting on the seals, the following discussion is made in connection with the schematic views of FIGS. 3 and 4.

In discussing the effect of forces upon a body, it is customary to consider that body as removed from all surrounding constraints. Each constraint is replaced by a force indicating its effect on that body. The resulting body is known as a "free body"; the study of forces with respect to that body is known as a "free body analysis." It is well known that a free body analysis can be made of a mechanical body. In this manner, a free body analysis can be made, for example, of a rotor or any part carried by the rotor, such as the apex seals. In the following discussion a free body analysis is made of the apex seals 54 carried by the rotor 24. Primed reference numerals are used in FIGS. 3 and 4 to indicate parts which are similar to parts of the rotary engine 10 of FIGS. 1 and 2.

Newton's First Law of Motion states that: A body at rest remains at rest, and a body in motion continues to move at constant speed along a straight line, unless there is a resultant force acting upon the body.

A body moving in a curved path is accelerated because its velocity is changing continually in direction, even though the body travels at a constant speed. This change is one of direction and not magnitude. Thus, if the path is continually changing in direction, additions are continually being made even though the magnitude of the velocity remains the same.

If a body is to proceed from one point to another point on a curved path, maintaining the same magnitude of velocity at both points, an added force will be required. An acceleration is associated with the motion of the body as the added force. The direction of this added force and acceleration is toward the center of curvature of the path.

The acceleration toward the center of curvature of the path is called "centripetal acceleration." It is well known that force is equal to mass times the acceleration. Thus, a force can be assumed to be acting upon the body; this force is also directed toward the center of curvature and is called "centripetal force."

Since for any action there is an equal and opposite reaction (Newton's Third Law of Motion), the moving body exerts an equal and opposite force upon the constraining agent in a direction radially away from the center of curvature. This reaction to the centripetal force is called "centrifugal force." Said in other words, when a body moves in a curved path, the force upon that body acting in a direction toward center of curvature, that path is called "centripetal force;" the force applied by the body in reaction to the centripetal force, is termed "centrifugal force."

There is shown in FIGS. 3 and 4, a free body 54', which may be any shape (shown in the general shape of an apex seal 54), traveling along a curved path from point A toward point G. In the direction of arrows 66'. The curved path A-G is in the form of a compound
The free body 54' is shown in Fig. 3 to be of an integrally formed design, and is located along this curve A-G, namely at points B, C, E, and F. An arrow Lb is a straight line tangent to the curve at point B and indicates the instantaneous direction of travel of the free body 54'. If the free body 54' is to travel along the curved path A-G from point B, rather than in the direction of arrow Lb, a centripetal force must be applied to it. This force, represented by the arrow Fe, provides the free body 54' with an inward component of motion toward the instantaneous center of curvature of the path at point B.

In the same manner, the arrow Le is a straight line tangent to the curve and indicates the instantaneous direction of travel of the body 54' at point C. If the free body 54' is to travel along the curved path A-G from point C, rather than in the direction of arrow Le, a centripetal force represented by the arrow Fc must be applied to provide the free body 54' with an inward motion toward the instantaneous center of curvature of the curved path at point C.

Thus, a force directed toward the instantaneous center of curvature must be applied to constrain the free body 54' in its natural path of following a straight line tangent to the path A-D.

Consider now the situation at the point E. Point E is just beyond the point of inflection D on the path A-G. The arrow Le is a straight line tangent to the curve at point E and indicates the instantaneous direction of travel of the free body 54'. Once again, if the free body 54' is to travel along the curved path A-G to G from point E, rather than in the direction of the arrow Le, a centripetal force, represented by the arrow Fc, must be applied. This force Fc provides a component of motion directed inwardly toward the instantaneous center of curvature of the curved path A-G at point E. It should be noted that the curvature of the path A-G reverses beyond the inflection point D. Therefore, the instantaneous centers of the path portion D-G are on an opposite side from the instantaneous centers of the portion A-D of the path A-G.

At point F, the situation is substantially the same as point E. The arrow Lf is a straight line tangent to the curve and indicates the instantaneous direction of travel of the free body 54' at point E. If the free body 54' is to travel along the curved path A-G, rather than in the direction of arrow Lf, a centripetal force, represented by the arrow Ff, must be applied to the body 54' to provide an inward motion toward the instantaneous center of curvature of the curved path at point F.

As the body 54' passes along the path A-G, it tends to travel in a straight line tangent to the curved path at any instantaneous point. In order that the body 54' be constrained to travel along the curved path A-G, a centripetal force must be applied at each instantaneous point. Since, as has been previously explained, the direction of the required centripetal force is always toward the instantaneous center of curvature of the compound curved path A-G of travel of the free body 54', and since the instantaneous centers will be found first on one side and then on the other side of the path A-G, then the direction of the centripetal forces constraining the moving free body 54' at four different reverse as the body travels past the four beat point D.

As explained above, centrifugal force is a reaction force of a body, equal and opposite to the centripetal force upon it; therefore, it follows that, if the centripetal force upon the free body 54' reverses direction as the free body 54' travels past the four beat point D, the centrifugal force of that body 54' must reverse as well.

Both Figs. 3 and 4 show the compound curve A-G (substantially in the form of a portion of the profile of the epitrochoidal surface of the peripheral wall 18 of Fig. 1). For simplicity in Fig. 4 a seal body 54" (the free body 54' of Fig. 3) is shown only at points C and F. This seal body 54" is illustrated as being within a slot 52' of an apex portion 24 of a seal body 54', as shown in Fig. 5.

For purposes of the discussion, the apex seals 54" of Fig. 4 are assumed to be being pushed by a side wall 68' of the slot 52' at a constant linear speed along the compound curved surface A-G of a peripheral wall 18'. In common practice, however, the apex seals 54', due to the motion of the rotor 24', will move at varying speeds. Such changes will not vary the sense of the forces being discussed herein. As indicated above with reference to Fig. 3, the sense of the centripetal forces will be directed toward the instantaneous center of curvature. For example, at point C, in the absence of a peripheral wall 18' of an outer body (and neglecting friction between the seal body 54' and the walls of the slot 52'), the seal body 54', pushed by the rotor 24', would travel in a straight line in the direction of the arrow Le. The peripheral wall 18', however, prevents the seal body 54' from traveling in such a direction. The wall 18' forces or constrains the seal body 54' to travel along the curved path A-G. Thus, at point C, as well as at each instantaneous point along the portion of the curved path A-D, the centripetal forces of the peripheral wall 18' constrain the seal body 54'. The equal and opposite forces of the centripetal force is shown in Fig. 4 by the arrow Fc. Similarly, at point F the seal body 54', in the absence of a centripetal force, would travel along a straight line in the direction of the arrow Lf. As shown in Fig. 3 a centripetal force at point F (arrow Ff shown in Fig. 3) is directed toward the instantaneous center of curvature and outwardly relative to the rotor axis 36 and shaft axis 22 (shown in Fig. 1).

The peripheral wall 18' cannot provide an outward centripetal force on the seal body 54'. To provide the outward centripetal force, a spring 60 (assisted by the effect of any gas pressure) is provided between the seal body 54' and the bottom wall 70' with the side walls of the groove 52'. The spring 60 is designed to exert an outward force (arrow Fr) on the seal body 54' which is sufficient in magnitude to provide the centripetal force necessary to force the seal to travel along the convex paths at the point F and in addition to insure adequate contact pressure between the seal body 54' and the peripheral wall 18' in all positions of the seal body 54' along its path of travel.

Neglecting any friction between the seal body 54' and the side wall 68' of the slot 52', the contact pressure at point E is equal to the difference between the force Fr exerted by the spring 60' on the seal body 54', and the centrifugal reaction force occurring at point F. This relationship will hold at each point along the convex portion 64' of the peripheral wall 18'. At every other point, such as the concave portion 62' of the peripheral wall 18', however, the spring force and the centrifugal force (arrows Fv and Fc, respectively) will both act in the same direction, urging the seal against the epitrochoidal inner surface 18' and the convex surfaces.

The contact pressure of the seal body 54' against the curved surface A-G of the peripheral wall 18' at point C is equal to the sum of the spring force Fr and the centrifugal force Fc. Therefore, along the convex portions 62' the seal contact pressure against the peripheral wall 18' is greater than the contact pressure at the convex portions 64'. Accordingly, if the contact pressure of the seal member 54' is adequate at a point on the convex portion 64', such as at point F, it may become excessive at points on the concave portion 62', such as point C.

Gas leakage past seals is a function of time. As the rotational rate increases, there is less time for gas to escape from the working chambers. Therefore, as the rate of rotation is increased, the necessity for close-sealing engagement between the apex seals 54 and the peripheral wall 18 diminishes. Sealing contact, useful at low speeds,
will introduce at high speeds undesirable housing and seal wear and increase a loss of power due to friction.

The present invention, as hereinafter discussed, is designed to provide adequate sealing contact pressure at lower speeds and to minimize the contact pressure between apex seals 54 and the peripheral wall 18 at higher speeds. The resulting effect is to decrease housing and seal wear and materially improve engine efficiency at the higher speeds.

FIG. 5 shows an enlarged view of the apex portion 30 of the rotor 24 of FIG. 2. The seal structure mechanism of FIG. 5 includes a hollow tube 72 disposed within the rotor 24 parallel to the rotor axis 36 and in the radial plane of the apex seal 54. The tube 72 is open at both ends and extends from one end face 26 to the other end face 28 of the rotor 24. Apertures 74 are spaced from both ends and at that part of the tube 72 which is radially near the apex seal 54.

Two lever arms 76 are shown within the tube 72 and extend axially therewith. The lever arms 76, like the tube 73, are arranged parallel to the rotor axis 36 and in the general radial plane of the apex seal 54. The tube 72 serves to transfer the lever arms 76, contained within the inner portion of the rotor 24. These lever arms 76 have their axially outward ends 78 forked (section in FIG. 5 shows only one of the two times). The ends 78 are so positioned as to be aligned with the apertures 74. The other end of each lever arm 76 is appropriately weighted to engage the weighted ends 80. The lever arms 76 are pivoted between their ends by means of bolts, pins, or similar means 82 near the forked ends 78. The bolts 82 extend perpendicularly with respect to the rotor axis 36 and transversely to the seal slot, and are mounted to the sides of the tube 72.

The apex seal 54 is shown in FIG. 5 in the apex slot 52 with the apex seal pins 56 inserted within each end face 26 and 28. Rotor apertures 86 extend from behind the seal pins 56 toward the interior part of the rotor 24. The apertures 74 of the tube 72 are in registry with the apertures 86 of the rotor 24.

The lever arms 76, shown in FIGS. 1 and 5, are symmetrically arranged in each apex portion 30 of the rotor 24 with respect to each other, the rotor axis 35, the rotor end faces 22 and 24, and the apex seal 54. Such symmetry prevents unbalanced rotation of the rotor 24.

Each apex seal 54 has a flared projection 88 near each end, extending radially into the rotor and through the registered apertures 74 and 86 into the tube 72. The forked ends 78 of the lever arms 76 straddle these fingers 88 and are retained in engagement by stops 90 borne by the fingers 88 of the tube 72. The ends 26 and 28 of the rotor 24 can be sealed by, for example, plugs or caps 92. The arrangement of the caps 92 and the tube 72 permits ease in assembly and repair. Thus, for example, the lever arms 76 are made accessible without further dismantling of the engine 10.

The lever arms 76 are pivotally mounted so as to move in response to the movement of the rotor 24. As each apex portion 30 moves along the concave and convex portions 62 and 64, of the peripheral wall 18, the effect of inertia is experienced by the lever arms 76. The inertia of the weighted ends 80 tends to cause them to swing outwardly and inwardly relative to the rotor axis 36 thereby causing the lever arms 76 to pivot about their axes 82.

An outward movement of the weighted ends 80 will cause the forked ends 78 to move inwardly and engage the stops 90 on the fingers 88 of the apex seal 54. Upon engaging these stops 90, the force of centrifugal force will urge the apex seal 54 inwardly with respect to the rotor 24.

An inward movement of the weighted ends 80 will cause the forked ends 78 to move outwardly disengaging the stops and not affect the position of the apex seal 54 with respect to the rotor 24 or the peripheral wall 18.

In order to reduce the contact pressure of the apex seal 54 against the peripheral wall 18, the force applied by the lever arms 76, as a result of the motion and mass of the weighted ends 80, must be sufficient to overcome the combined effects of the stiffness of the spring 60, the gas pressure in the slots 52, and the mass of the apex seal 54. The stiffness of the spring 60 is selected so as to restrain the apex seal 54 against the downward force applied by the forked ends 78 of the lever arms 76 against the stops 90 at or below a predetermined rotational speed.

At a desired relatively high speed, the weighted ends 80 of the lever arms 76 will pivotally move in an outward direction when the apex portion 30 enters upon the concave portion 62 of the peripheral wall 18 overcoming the stiffness of the spring 60 and the gas pressure. The forked ends 78, engaging the stops 90, will force the apex seal 54 to move inwardly with respect to the rotor 24 minimizing the contact pressure between the apex seal 54 and the peripheral wall 18.

Upon the rotor apex portion 30 entering the convex portion 64, the weighted ends 80 will swing inwardly with respect to the rotor 24 causing the forked ends 78 to move outwardly. In making such a movement the forked ends 78 will not engage the apex seal 54 and the seal will have a contact pressure exerted by the combined spring and in the new position.

The lever arms 76 as shown in FIGS. 2 and 5 are arranged in the apex portion 30, in the radial plane of the apex seal 54, and parallel to the rotor axis 36. In this position the force of the acceleration forces upon the apex seal 54 must be substantially the same instant of time that the weighted ends 80 of the lever arms 76 will pivotally change the direction of their movement with respect to the rotor 24.

At lower rotational speeds, the effect of the lever arms 76 will reduce contact pressure between the apex seal 54 and the peripheral wall 18. As has been previously discussed, it is desirable to withdraw the apex seal 54 from contact at relatively higher rotational speeds to improve engine efficiency and decrease apex seal and peripheral wall wear. Such withdrawals are effected by the lever arms 76. As the rotational speeds increase, it follows that the acceleration and deceleration forces increase. Thus, the masses of the apex seal 54 and the weighted ends 80 of the lever arms 76 become of greater effect upon the position of apex seal 54 with respect to the rotor 24 than the substantially constant force of the spring 60.

The planes of the weighted ends 80 is of such magnitude as to withdraw the apex seal 54 from contact with the peripheral wall 18 at the relatively high speeds.

What is claimed is:

1. In a rotary combustion engine of the type having an outer bowl defining an internal cavity having a central axis, and a rotor mounted therein for rotation with respect to the outer body on a rotor axis planating about the central axis, the rotor having a plurality of apex portions, the profiles of the rotor and the peripheral wall of the outer body defining therebetween a plurality of variable-volume working chambers, means for sealing the apex portions of the rotor to the inner surface of the peripheral wall, comprising:

(a) means carried by each rotor apex for forming a seal between the apex portions and the peripheral wall, the seal-forming means being radially moveable relative to the rotor for maintaining sealing contact with the peripheral wall;

(b) force-reducing means carried by each rotor apex portion and associated with the seal-forming means thereof for reducing contact pressure of the seal-forming means against the peripheral wall, including at least one lever

(i) having first and second portions and being pivotally mounted therewith,

(ii) the first portion being of greater mass than the second portion and responsive to centrifugal force

(iii) the second portion being operatively connected to the seal-forming means to apply a
radially inward force thereon when centrifugal force on the first portion is directed radially outwardly relative to the central axis.

2. Means for sealing as recited in claim 1, including a spring normally urging the seal-forming means in a radially outward direction relative to the rotor, the spring being selected to have a spring force which is partially counteracted by the force-reducing means at low engine speeds to reduce contact pressure of the seal-forming means when centrifugal force on the first lever portion is directed radially outwardly relative to the central axis.

3. Means for sealing as recited in claim 2, wherein at a higher predetermined engine speed the seal-forming means is relieved from contact with the peripheral wall when centrifugal force on the first lever portion is directed radially outwardly relative to the central axis.

4. Means for sealing as recited in claim 2, wherein the peripheral wall has at least one concave portion, the force-reducing means being operative when the seal-forming means is in contact with the concave portion.

5. Means for sealing as recited in claim 2, wherein the peripheral wall has at least one concave portion and at least one convex portion, the force-reducing means exerting a radially inward force on the seal-forming means when the seal-forming means is traversing the concave portion.

6. Means for sealing as recited in claim 1, wherein the seal-forming means is a seal strip extending parallel to the rotor axis and having an inwardly directed projection near each end and there are two levers each having its second portion engaged with one of the seal strip projections.

7. Means for sealing as recited in claim 6, wherein the second portions of the levers engage the seal strip projections only when centrifugal force on the first lever portion is directed radially outwardly, and the seal strip projections are free of such engagement when centrifugal force is directed radially inwardly.

8. The combination recited in claim 7, wherein each second lever portion has a forked end spanning the seal strip projection, and each seal strip projection has a stop member disposed radially inwardly of the forked end against which the forked end exerts radially inward force when centrifugal force is directed radially outwardly on the first lever portion and on the seal strip, the seal strip projection being freely movable in the radially inward direction within the forked end when centrifugal force is directed radially inwardly.

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