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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

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(54) **Title**: DUAL TIP SEALS FOR A ROTARY ENGINE

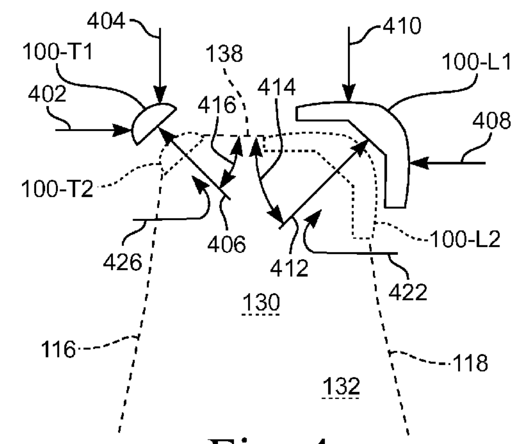

Fig. 4

(57) **Abstract**: A biased dual tip seal arrangement for the rotor (106) of a rotary engine (102). The dual tip seals (100-T, 100-L) are located on opposite corners of the tip (130) of a planetary rotor (106). The rotor (106) orbits within a cutout (126) in a main rotor (108). The seals (100-T, 100-L) are biased away from the corners to make sealing contact with the sealing surfaces of the asymmetrical lobe (112) and the cutout (126) of the main rotor (108). Biasing is implemented with springs (1202, 1302, 1412) and with conduits (1006) that pressurize the area under the seals (100-T, 100-L). An asymmetrical lobe (112') includes a transition zone (802) on the surface of the lobe (112). In the transition zone (802), at least one seal (100-T, 100-L) on the tip (130) maintains contact with the surface (112') while alternating contact from one seal (100-T, 100-L) to the other.

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TITLE OF INVENTION

Dual tip seals for a rotary engine

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/475,966, filed April 15, 2011.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable

BACKGROUND OF THE INVENTION

1. Field of Invention

[0003] This invention pertains to seals within a rotary engine. More particularly, this invention pertains to the tip seals on the rotor of a rotary engine.

2. Description of the Related Art

[0004] Rotary engines, such as the rotary planetary engines disclosed in U.S. Patents 6,932,047; 7,044,102; 7,350,501; 7,614,382; and 8,109,252 have rotating and orbiting elements that wipe or slide across an inside surface of the engine. Such types of rotary engines have a main rotor with circular cutouts. Inside each circular cutout is a planetary rotor that orbits the center of rotation of the main rotor. The planetary rotor has faces that sequentially cycle through intake, compression, combustion, and exhaust. Other rotary engines include those such as the Wankel engine. These engines operate with a different configuration than described herein. For example, the Wankel-type engines operate with a rotor mounted on an eccentric with the rotor moving within a two-lobed cavity.

[0005] Unlike reciprocating engines that have piston rings that provide a seal between moving parts, rotary engines have multiple surfaces moving against each other in a non-linear fashion. The interface between these surfaces require a seal in order for the combustion chamber to maintain compression.

BRIEF SUMMARY OF THE INVENTION

[0006] According to one embodiment of the present invention, a leading corner seal and a trailing corner seal for a planetary rotor tip is provided. The leading and trailing corner seals are biased away from the tip. In various embodiments, the leading and trailing corner seals are biased by springs.

[0007] One type of rotary engine includes an internal cavity, a main rotor, and a plurality of planetary rotors. The planetary rotors orbit around the main rotor. The main rotor has cutouts within which a planetary rotor rotates. Each planetary rotor has multiple vanes, which extend radially from the center of the planetary rotor and terminate at tips. Each vane has a leading face and a trailing face. The vane has a substantially squared-off tip where the two faces converge at the tip. The tips of the vanes have a tip surface and two corners; the leading corner and the trailing corner. The tip surface is bounded on each side by one of the two corners.

[0008] The internal cavity includes lobes that provide the surface on which the tips of the vanes pass during operation. The four internal combustion cycles of the rotary engine, intake, compression, combustion, and exhaust, occur in chambers defined, in part, by either a leading face or a trailing face. While one chamber provides an enclosure for combustion, the other chambers formed by the same rotor provide enclosures for other cycles. The planetary rotor is shaped such that the tip of each vane separates two such chambers.

[0009] The two chambers are separated by a vane having a dual tip seal arrangement. The dual tip seal arrangement includes a leading corner seal, or leading seal, and a trailing corner seal, or trailing seal. The seals maintain a pressure boundary and accommodate thermal expansion and the manufacturing tolerances of engine components. The leading corner seal extends along a portion of the surface of the tip and a portion of the leading face to form a raised surface at a corner of the vane. The leading corner seal has a variable radius surface that provides a smooth engagement of the sealing surfaces in the engine, while maintaining a compliant and durable seal. The trailing corner seal protrudes from the trailing corner of the tip and has a constant radius for sealing. The leading and trailing corner seals are biased away from the tip by a spring. In another embodiment, each seal is biased away from the tip by a port that extends from the adjacent side of the vane to the space under the seal. When the chamber defined by the adjacent side is pressurized, the force of the pressure pushes the seal away from the tip, thereby increasing the bias force. In this way, the leading and trailing corner seals accommodate dimensional variations caused by thermal expansion of the various components and manufacturing tolerances.

[0010] For a rotary engine, the housing defines an asymmetrical lobe that provides a transition zone where the leading corner seal and the trailing corner seal in the tip of the rotor alternate engagement with the surface of the lobe. The transition zone lies between a trailing zone and a leading zone. The leading corner seal performs the sealing function while the tip traverses the leading zone. The trailing corner seal performs the sealing function while the tip traverses the trailing zone. In the transition region, both the leading and the trailing corner seals engage the lobe as the vane transitions from the trailing seal to the leading seal. In this way, a sealed interface is maintained between the tips of the vanes and the sealing surface of the lobe as the tips traverse the leading, transition, and trailing zones.

[0011] The leading and trailing corner seals are contoured such that the gap between the tip of the planetary rotor and the sealing surface of the lobe, or lobe surface, is filled. The lobe is asymmetric in that each arcuate section of the lobe includes a blended region that joins two dissimilar radii, one radius forming the leading zone and the other radius forming the trailing zone. The blended region is the transition zone. The transition zone is where the leading seal transitions from the free state to the sealing state and the trailing seal transitions from the sealing state to the free state. In the trailing zone, the trailing corner seal is in the sealing state, that is, it bears on the lobe surface to separate the two chambers divided by the vane. Also, in the trailing zone, the leading edge seal is in the free state, that is, the leading edge seal is not in contact with the lobe surface. In the leading zone, the leading corner seal is in the sealing state and the trailing corner seal is in the free state. In the transition zone, the leading and trailing corner seals are both in contact with the lobe surface.

[0012] The leading corner seal is configured to fill a leading gap between the planetary rotor and the lobe surface and the sealing surface of the cutout, or forward surface, in the main rotor. The leading gap develops as the tip of the planetary rotor moves from the leading zone of lobe surface to the forward surface of the cutout. As the main rotor approaches the bridge, the leading corner seal fills the gap between the outer rim of the main rotor and the bridge until the outer rim forms a dynamic seal with the bridge.

[0013] The trailing corner seal has an arcuate surface that projects away from the trailing corner of the tip. A trailing gap develops when the tip of the planetary rotor moves from the rear surface of the cutout onto the trailing zone of the lobe surface. Similar to the leading gap, the trailing gap is also an opening between the outer rim of the main rotor and the bridge. The trailing corner of the vane approaches the trailing zone of the lobe surface in a tangent path such that an arcuate shape is sufficient to maintain a seal between the chambers on either side of the vane. In this way, the tip of the planetary rotor separates the two chambers divided by a vane as it enters and exits the cutout of the main rotor.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0014] The above-mentioned features of the invention will become more clearly understood from the following detailed description of the invention read together with the drawings in which:

[0015] FIG. 1 is an internal view of one embodiment of a rotary engine having multiple planetary rotors with dual tip seals;

[0016] FIGS. 2A is an internal view of the planetary rotors with a vertical tip about to enter the main rotor cutout;

[0017] FIGS. 2B is an internal view of the planetary rotors with a vertical tip about to exit the main rotor cutout;

[0018] FIGS. 2C is an internal view of the planetary rotors with a vertical tip adjacent a transition zone;

[0019] FIG. 3 is a partial plan view of the tip in the position illustrated in FIG. 2A where the vertical tip is moving from the lobe surface to the forward surface of the cutout;

[0020] FIG. 4 is a symbolic view of the seals showing the balance of forces and range of motion of the leading and trailing corner seals during operation of the rotary engine;

[0021] FIG. 5A-D are partial plan views representing the progression of a tip moving from the lobe surface to the forward surface of the cutout;

[0022] FIG. 6 is a partial plan view of a tip in the position illustrated in FIG. 2B where the tip is moving from the rear surface of the cutout to the lobe;

[0023] FIGS. 7A-B are partial plan views representing the progression of a tip moving from the rear surface of the cutout to the lobe;

[0024] FIG. 8 is a partial plan view of one embodiment of a lobe that is asymmetrical;

[0025] FIG. 9 is a partial plan view of the asymmetrical lobe of FIG. 8 with a tip traversing the transition region;

[0026] FIG. 10 is a perspective view of the tip shown in FIG. 3 with the end cap removed;

[0027] FIG. 11 is a perspective view of the back side of the end cap;

[0028] FIG. 12 is an exploded partial cross-sectional view of one embodiment of the corner seals with helical springs; and

[0029] FIG. 13 is an exploded view of another embodiment of the corner seals with wave springs.

[0030] FIG. 14 is a partial plan view of another embodiment of a planetary rotor showing another embodiment of the seals and end cap;

[0031] FIG. 15 is a partial perspective view of the embodiment of the planetary rotor illustrated in FIG. 14;

[0032] FIG. 16 is a perspective view of the embodiment of the end cap illustrated in FIG. 14;

[0033] FIG. 17 is a partial plan view of the embodiment of the planetary rotor illustrated in FIG. 14;

[0034] FIG. 18 is a plan view of the embodiment of the trailing tip seal illustrated in FIG. 14;

[0035] FIG. 19 is a side view of the embodiment of the trailing tip seal illustrated in FIG. 14;

[0036] FIG. 20 is a plan view of the embodiment of the leading tip seal illustrated in FIG. 14;

[0037] FIG. 21 is a side view of the embodiment of the leading tip seal illustrated in FIG. 14;

[0038] FIG. 22 is a partial plan view of another embodiment of the main rotor;

[0039] FIG. 23 is a partial plan view of one embodiment of a housing showing the side seal,

[0040] FIG. 24 is a perspective view of one embodiment of a housing button seal; and

[0041] FIG. 25 is a plan view of one embodiment of a spring washer.

DETAILED DESCRIPTION OF THE INVENTION

[0042] An apparatus for dual tip seals for the rotor of a rotary engine is disclosed. The embodiment illustrated in the figures is a pair of dual tip seals used in a rotary engine where planetary rotors orbit around the main rotor. As used herein, the suffixes or the hash or apostrophe appended to a reference number indicate a particular embodiment or configuration of a component. When the reference number is used without the suffix, the generic component is being referenced, for example the seal **100** refers generically to the seals, whereas **100-T**, **100-L**, etc. refer to specific configurations of the two seals **100**.

[0043] FIG. **1** illustrates an internal view of one embodiment of a rotary engine **102** having multiple planetary rotors **104** with dual tip seals **100-T**, **100-L**. The rotary engine **102** includes a housing **104**, a main rotor **108**, and a plurality of planetary rotors **106**. The housing **104** has an internal cavity **124** in which rotates the main rotor **108**. The main rotor **108** has three cutouts **126** in which the planetary rotors **106** orbit about the main shaft **110**. The illustrated engine is a planetary piston rotary engine, such as that disclosed in United States Patents 6,932,047; 7,044,102; 7,350,501; 7,614,382; and 8,109,252, all incorporated by reference. However, those skilled in the art will recognize that the invention is not limited to use only with such rotary engines.

[0044] The internal cavity **124** is defined by three lobes **112**. Each lobe **112** has one fuel injector **141** that provides fuel for combustion in the engine **102**. Each pair of adjacent lobes **112** is joined at a bridge **114**. The main rotor **108** rotates clockwise **122** on the main shaft **110** inside the housing cavity **124**. The main rotor **108** has three circular cutouts **126** that each contain one planetary rotor **106**. The main rotor **108** also has three sections of outer rim **128** that engage the bridge **114** during selected positions of the main rotor **108** as the main rotor **108** rotates inside the cavity **124**.

[0045] Each planetary rotor **106** has three vanes **132**, which extend radially from the center of the planetary rotor **106** and terminate at tips **130**. The tips **130** have a tip surface **138** and two corners: the leading corner **134** and the trailing corner **136**. The tip surface **138** is bounded on each side by one of the two corners **134**, **136**. Each vane **132** has a first face **116** and a second face **118**. The two faces **116**, **118** converge at the tip surface **138**. The four engine cycles of the rotary engine **102**, intake, compression, combustion, and exhaust, occur in chambers **140** defined, in part, by either a first face **116** or a second face **118**. The planetary rotor **106** is shaped such that the tip **130** of each vane **132** separates two such chambers **140-A**, **140-B**.

[0046] As illustrated in FIG. 1, the planetary rotors **106** orbit in the clockwise direction **122** around the main shaft **110** inside the cutouts **126** of the main rotor **108**. Each planetary rotor **106** does not rotate about its shaft **120**, but maintains a stationary position relative to the shaft **120**. That is, the first face **116** of the planetary rotor **106** shown facing downward in FIG. 1, remains facing downward as the planetary rotor **106** orbits the main shaft **110**. The main shaft **110** and the planetary rotor shafts **120** are connected to a planetary gear assembly (not illustrated) that maintains the orbital position of the planetary rotors **106** as they orbit the main shaft **110**.

[0047] The illustrated rotary engine **102** operates with three planetary rotors **106** that are located 120 degrees apart. Each planetary rotor **106** has three vanes **132** that are located 120 degrees apart, each one having dual tip seals **100-T**, **100-L**. The following discussion is applicable to each of the vanes

132 on each of the planetary rotors **106** at some point along a 120 degree rotation of the main rotor **108** even though the discussion will now focus on a single tip having dual tip seals **100-T**, **100-L**.

[0048] FIGS. **2A-C** illustrate internal views of the rotor **108** and planetary rotors **106** at different positions as the planetary rotor **106-A** orbits within the rotary engine **102**. In the figures, the main rotor **108** rotates clockwise **122**. The reference line **202** identifies the orientation of a single arm of the main rotor **108**. As the main rotor **108** rotates about the main shaft **110**, the reference line **202** moves with the main rotor **108**.

[0049] In FIG. 2A, the reference line **202-A** is at about the one o'clock position. The tip **130-A** of the planetary rotor **106-A** is shown in a position as it transitions from the lobe **112** to the cutout **126**. The tip **130-A** is always pointing upward as shown throughout the orbit of the planetary rotor **106-A**. The cutout **126** is shaped to provide a surface on which the tip **130-A** traverses during the orbit of the planetary rotor **106-A**. The surface of the cutout **126** that receives the tip **130** of a planetary rotor **106** at the illustrated transition is the forward surface **204**. The positions of the tip **130-A**, the cutout **126**, and lobe **112** are fixed such that manufacturing tolerances and thermal expansion result in gaps between the tip **130-A** and the surfaces of the cutout **126** and the lobe **112**. The tip seals **100-L**, **100-T** are biased away from the tip **130-A** to maintain a compliant and durable seal throughout the orbit of the planetary rotor **106-A** around the main shaft **110**.

[0050] In FIG. 2B, the reference line **202-B** is at about the seven o'clock position. The tip **130-A** traverses the cutout **126** from the forward surface **204** to the rear surface **206** during the rotation of the rotor **108** from the reference lines **202-A** and the reference line **202-B**. The surface of the cutout **126** where the tip **130** of a planetary rotor **106** leaves the cutout **126** is the rear surface **206**. The tip **130-A** is shown in a position as it transitions from the rear surface **206** to the lobe **112**. The cutout **126** is a continuous, smooth radius. The leading and trailing corner seals **100-L**, **100-T** are both in continuous contact with the cutout **126** during traversal of the cutout **126**. When the tip **130-A** transitions from the rear surface **206** to the lobe **112**, the trailing corner seal **100-T** contacts the lobe **112**.

[0051] In FIG. 2C, the reference line **202-C** is at about the 10 o'clock position. The tip **130-A** is at the center of the lobe **112**. At the center of the lobe **112**, the leading and trailing corner seals **100-L**, **100-T** are both in contact with the lobe **112**. As the tip **130-A** approaches the center of the lobe **112**, the leading corner seal **100-L** gradually moves from a free state, that is, a state where no contact is made with a surface, closer to the lobe **112** until it transitions to a sealing state where contact is made with the lobe **112**. As the tip **130-A** moves from the position illustrated in FIG. 2C to the position illustrated in FIG. 2A, the trailing corner seal **100-T** gradually moves away from the lobe **112** transitioning from a sealing state to the free state where it is no longer in contact with the lobe **112**.

[0052] FIG. **3** illustrates a partial plan view of the tip **130-A** in the position illustrated in FIG. 2A where the tip **130-A** is moving from the lobe **112** to the forward surface **204** of the cutout **126**. The tip **130-A** includes a leading seal **100-L** and a trailing seal **100-T**. The leading seal **100-L** projects beyond the tip surface **138** and projects beyond the second surface **118**. The projecting surface of the leading seal **100-L** has a contour shaped to maintain a sealing connection with the cutout **126** and the lobes **112**. The illustrated embodiment of the trailing seal **100-T** has a arcuate shape that protrudes beyond the tip surface **138** and the first surface **116**.

[0053] The forward surface **204** of the cutout **126** is in contact with the corner seals **100**. The corner seals **100** are biased away from the tip **130-A** such that a sealing connection is maintained at the forward surface **204**. The leading corner seal **100-L** is also in contact with the lobe **112**. The leading corner seal **100-L** is biased away from the tip **130-A** such that a sealing connection is maintained with the lobe **112**. The leading corner seal **100-L** is a boundary between the two chambers **140-A**, **140-B**. The leading corner seal **100-L** seals the interface between the tip **130-A** and the forward surface **204** and between the first face **116** and the lobe **112**.

[0054] The vane **132** includes an end cap **306**. The end cap **306** retains the leading and trailing corner seals **100-L**, **100-T**. In the illustrated embodiment, the end cap **306** is secured to the vane **132** by two fasteners **308**. In another embodiment, the cover is retained by one fastener **308**. In other embodiments, the end cap **306** is retained by an adhesive, or the end cap **306** is welded to the vane, or the end cap **306** is retained by a friction fit.

[0055] In the illustration, the instantaneous direction **302-1** of the tip **130-A** is substantially downward. The instantaneous direction **122-1** of the forward surface **204** is downward, and also angled toward the tip **130**.

[0056] FIG. **4** illustrates a partial plan view of a tip **130** showing the balance of forces and range of motion of the leading and trailing corner seals **100-L**, **100-T** during operation of the rotary engine **102**. The leading and trailing corner seals **100-L**, **100-T** are rigid bodies such that any force causing a part of the body to move causes the whole body to move together. The leading and trailing corner seals **100-L**, **100-T** are biased to move away from the tip **130** at angles **414**, **416**. In the illustrated embodiment, the leading corner seal **100-L** is angled approximately 42.5 degrees **414** from the surface **138** of the tip **130** and the trailing corner seal **100-T** is angled approximately 45 degrees **416** from the surface **138** of the tip **130**. In various embodiments, the angles **414** and **416** vary to accommodate the engine configuration and performance requirements.

[0057] The leading and trailing corner seals **100-L**, **100-T** are biased away from the tip **130**. The corner seals **100-L1**, **100-T1** are shown in the free state position where the seals **100-L1**, **100-T1** are restrained from moving beyond a specified distance from the tip **130**. When providing a sealing connection, the corner seals **100-L**, **100-T** are depressed toward the tip **130** according to the gap between the surfaces being sealed. The corner seals **100-L2**, **100-T2** (shown with dashed lines) are in the fully depressed state position where the corner seals **100-L2**, **100-T2** are restrained from being depressed further. The fully depressed position is where the outer surfaces of the corner seals **100-L2**, **100-T2** still protrude beyond the surfaces **116**, **118**, **138** of the tip **130**.The locations of the corner seals **100-L**, **100-T** are exaggerated in the figure for illustration purposes. In one embodiment, the maximum travel from the free state to the fully depressed state is approximately 0.004 inches.

[0058] The corner seals **100** are restrained in their movement such that they travel in the direction of the biasing force vectors **406**, **412**. The tip **130** and the two faces **116**, **118** of the vane **132** encounter opposing surfaces of the lobe **112** and the cutout **126** during the engine cycle. The gap between the components **112**, **116**, **118**, **126**, **130** varies according to the manufacturing tolerances, thermal expansion caused by the heat generated by the operating engine **102**, and component wear. The corner seals **100** are biased to move to fill the gap by contacting the opposing surface. The corner seal biasing force is shown as force vectors **406**, **412**. In various embodiments, the biasing force **406**, **412** has two components, namely, a spring bias and a pressure bias force **426**, **422** from the pressure in the adjacent chamber. The biasing force vectors **406**, **412** are balanced by the contact force vectors **402**, **404**, **408**, **410**.

[0059] As the gap between the tip **138** and the other surface **112**, **204** varies, the contact force vectors **402**, **404**, **408**, **410** applied to the leading and trailing corner seals **100-L**, **100-T** varie. During the engine cycle, forces at various angles are applied to the leading and trailing corner seals **100-L**, **100-T**. For illustration purposes, the forces experienced by the leading and trailing corner seals **100-L**, **100-T** are broken down into their basic x-axis **402**, **408** and y-axis **404**, **410** components. The biasing force vectors **406**, **412** oppose the contact force vectors **402**, **404**, **408**, **410** encountered during the engine cycle such that a compliant and durable seal is maintained.

[0060] For example, in FIG. 3, the contact force vectors **402**, **404** are the components of the force applied to the trailing seal **100-T** by the presence of the forward surface **204** of the main rotor **108** and the sliding, or frictional, force applied by the relative motion between the trailing seal **100-T** and the forward surface **204**. The contact force vectors **408** and **410** applied to the leading seal **100-L** also arise, in part, from the presence of the forward surface **204** and the sliding, or frictional, force applied by the relative motion between the leading seal **100-L** and the forward surface **204**. Additionally, the contact force vectors **408** and **410** arise from the presence of the lobe **112** and relative motion between the lobe **112** and leading seal **100-L**.

[0061] FIGS. **5A-D** illustrate partial plan views representing the progression of a tip **130-A** moving from the lobe **112** to the forward surface **204** of the cutout **126** as shown in FIG. 2A. Generally, the corner seals **100** are in contact with the lobe **112** and/or the cutout **126** throughout the engine cycle. The contact makes a sealing connection that isolates two chambers **140**. The configuration of the chamber **140** varies as the main rotor **108** rotates in the cavity.

[0062] In FIG. 5A, the leading corner seal **100-L** is in the sealing state because the leading corner seal **100-L** is in contact with the lobe **112**. The forward surface **204** of the cutout **126** in the main rotor **108** has made initial contact with the trailing corner seal **100-T**. The leading corner seal **100-L** forms a boundary between chambers **140-A** and **140-B**.

[0063] The arcuate shape of the trailing corner seal **100-T** provides a sufficient lead-in surface to prevent stubbing for the extreme case where the forward point **304** contacts the trailing corner seal **100-T**. The location in which the forward point **304** contacts the trailing corner seal **100-T** is such that the trailing corner seal **100-T** is depressed inward toward the trailing corner **134** of the vane **132**. The instantaneous direction **122-A** of the forward surface **204** is substantially downward with a component toward the lobe **112**. The instantaneous direction **302-A** of the tip **130** is generally downward and angled toward the lobe **112**. In other embodiments, the forward surface **204** has an arcuate configuration that allows the forward surface **204** to contact the trailing corner seal **100-T** at a point on the forward surface **204** away from the forward point **304**.

[0064] In FIG. 5B, the trailing corner seal **100-T** is in contact with the forward surface **204**. The leading corner seal **100-L** now forms a boundary between two chambers **140-A** and **140-B** The forward point **304** is located above the tip **130** and is nearer to the leading corner seal **100-L** than in FIG. 5A. The instantaneous direction **122-B** of the forward surface **204** is still downward at about 45 degrees toward the tip **130-A**. The instantaneous direction **302-B** of the tip **130-A** has changed to a substantially downward direction.

[0065] In FIG. 5C, the leading and trailing corner seals **100-L**, **100-T** are both in contact with the forward surface **204** of the cutout **126**. The main rotor **108** is in position for the outer rim **128** to move past the bridge **114**. The corner seals **100-L**, **100-T** form a boundary between two chambers **140-C** and **140-B**. The instantaneous direction **122-C** of the forward surface **204** continues to become more downward than shown in FIGS. 5A and 5B. The tip **130-A** has an instantaneous direction **302-C** that is substantially downward.

[0066] In FIG. 5D, the corner seals **100** are both in contact with the forward surface **204**. The vane **132** is no longer in contact with the lobe **112**. The forward surface **204** has an instantaneous direction **122-D** even more downward than shown in FIG. 5C. The instantaneous direction **302-D** of the tip **130-A** is downward with an inward component toward the midpoint of the cutout **126** in which it traverses.

[0067] FIG. **6** illustrates a partial plan view of a tip **130-A** in the position illustrated in FIG. 2B where the tip **130-A** is moving from the rear surface **206** of the cutout **126** to the lobe **112**. The rear surface **206** is in contact with the leading and trailing corner seals **100-L**, **100-T**. The lobe **112** is in contact with the trailing corner seal **100-T**. The corner seals **100-L**, **100-T** are biased away from the tip **130-A** such that a sealing connection is maintained at the rear surface **206** and the lobe **112**. The trailing corner seal **100-T** is a boundary between the two chambers **140-I**, **140-J**.

[0068] In the illustration, the instantaneous direction **302-2** of the tip **130-A** is substantially upward. The instantaneous direction **122-2** of the rear surface **206** is upward and angled away from the lobe **112**. The instantaneous directions **302-2**, **122-2** of the tip **130-A** and the rear surface **206** shown in the illustration are roughly opposite the instantaneous directions **302-2**, **122-2** of the tip **130-A** and the main rotor **108** shown in FIG. 3

[0069] FIGS. **7A-B** illustrate partial plan views representing the progression of a tip **130-A** moving from the rear surface **206** of the cutout **126** to the lobe **112**. In FIG. 7A, the corner seals **100** are both in contact with the rear surface **206**. The rear surface **206** has an instantaneous direction **122-E** substantially upward with an angle away from the lobe **112**. The instantaneous direction **302-E** of the tip **130** is substantially upward .

[0070] In FIG. 7B, the corner seals **100-L**, **100-T** have moved from full contact with the rear surface **206** to the trailing corner seal **100-T** making contact with the lobe **112**. The trailing corner seal **100-T** is in the sealing state, that is, the trailing corner seal **100-T** is in contact with the lobe **112**. The leading corner seal **100-L** is in the free state, that is, the leading corner seal **100-L** is fully extended outward, no longer contacting the rear surface **206**. The rear surface **206** has an instantaneous direction **122-F** substantially upward with an angle away from the lobe **112**. The instantaneous direction **302-F** of the tip **130-A** is generally upward tangent to the curve of the lobe **112**.

[0071] FIG. **8** illustrates a partial plan view of one embodiment of a lobe **112'** that is asymmetrical. FIG. **9** illustrates a partial plan view of the asymmetrical lobe **112'** of FIG. 8 with a tip **130** traversing the asymmetric lobe **112'**. The tip **130-A** shown in FIG. 2C is in the transition zone **802**. The transition zone **802** is the region on the lobe **112** where the tip **130** moves from the trailing zone **804** to the leading zone **806**. In the trailing zone **804**, the tip **130** is oriented such that the trailing corner seal **100-T** is in the sealing state and the leading corner seal **100-L** is in the free state. After passing through the transition zone **802** and reaching the leading zone **806**, the tip **130** is oriented such that the leading corner seal **100-L** is in the sealing state and the trailing corner seal **100-T** is in the free state.

[0072] Where the transition zone **802** is an extended length, a location exists on the lobe **112** where the leading and trailing corner seals **100-L**, **100-T** both are in the sealing state, that is, they both form a sealed connection with the lobe **112**. For example, where two radii **808**, **810** are joined at their tangent points by a straight line, the leading and trailing corner seals **100-L**, **100-T** both are in the sealing state, that is, they both form a sealed connection with the lobe **112**.

[0073] The asymmetric lobe **112'** is a cavity that lies within the housing **104** of a rotary engine **102**. The asymmetric lobe **112'** includes a trailing zone **804**, a transition zone **802**, and a leading zone **806** that combine to form a continuous arcuate shape. The trailing zone **804** has a radius **810**. The leading zone **806** has a radius **808**. The radii **808**, **810** are sized to meet the specific performance requirements of the rotary engine **102**. The trailing and leading zones **804**, **806** are sized such that the radii **808**, **810** are not necessarily identical.

[0074] The transition zone **802** is a region that joins the trailing and leading zones **804**, **806**. The transition zone **802** ensures that a continuous sealed connection exists between the lobe **112** and the tip **130**. In the illustrated embodiment, the trailing zone **804** is defined by a trailing center **822** and a radius **810**. The leading zone **806** is defined by a leading center **820** and a radius **808**. The trailing center **822** is offset **814-B** from the centerline **818** of the lobe **112**. The centerline **818** passes through the axis of rotation of the main rotor **108** and bisects the lobe **112**. The leading center **820** is offset **814-A** from the centerline **818** of the lobe **112** in the opposite direction relative to the trailing offset **814-B**. Also, the trailing center **822** is offset **812** along the centerline **818** from the leading center **820**.

[0075] The transition zone **802** varies according to the geometry and performance requirements of the rotary engine **102**. In one embodiment, the transition zone is asymmetric in both the x-axis and y-axis where the centers, **820**, **822** of the radii **808**, **810** are offset in both the x-axis **816** and at the centerline **818**. In one such embodiment, the trailing zone **804** has a 4.689 inch radius **810** and the leading zone **806** has a 4.706 inch radius **808**. The center **820** of the leading zone radius **808** has a 0.194 inch centerline offset **814-A**. The center **822** of the trailing radius **810** has a 0.283 inch centerline offset **814-B**. The centers **820**, **822** of the radii **808**, **810** have a 0.086 inch x-axis offset **812**.

[0076] FIG. **10** illustrates a perspective view of the tip **130** shown in FIG. 3 with the end cap **306** removed. FIG. **11** illustrates a perspective view of one embodiment of an end cap **306**. The tip **130** receives the two corner seals **100**. The two corner seals **100-T**, **100-L** are retained in the tip **130** by the end cap **306**. A retaining post **1002**, **1004** extends from each corner seal **100-T**, **100-L**.

[0077] Each end of the trailing seal **100-T** includes a retaining post **1002** extending from the surface **1012** of the vane **132**. The retaining post **1002** moves in concert with the trailing seal **100-T**. The retaining post **1002** is received by the opening **1102** in the end cap **306**. The opening **1102** in the end cap **306** restrains the retaining post **1002** from moving beyond predetermined limits. In particular, the opening **1102** holds the trailing seal **100-T** captive by preventing the retaining post **1002** from moving away from the vane **132** beyond the preset distance. With respect to movement of the trailing seal **100-T** in the depressed direction, in various embodiments the seal **100-T** is restrained by the opening **1102** or by bottoming out on the biasing device.

[0078] Each end of the leading seal **100-L** includes a pair of retaining posts **1004** extending from the surface **1012** of the vane **132**. The retaining posts **1004** move in concert with the leading seal **100-L**. The retaining posts **1004** are received by the opening **1104** in the end cap **306**. The opening **1104** in the end cap **306** restrains the retaining posts **1004** from moving beyond predetermined limits. In particular, the opening **1104** holds the leading seal **100-**

L captive by preventing the retaining posts **1004** from moving away from the vane **132** beyond the preset distance. With respect to movement of the leading seal **100-L** in the depressed direction, in various embodiments the leading seal **100-L** is restrained by the opening **1104** or by bottoming out on the biasing device.

[0079] The end cap **306** mates with the vane **132** at the vane surface **1012**. In the illustrated embodiment, the vane surface **1012** includes two threaded holes **1010**. The end cap **306** has two fastener holes **1104**. The threaded holes **1010** in the vane surface **1012** align with the fastener holes **1104** in the end cap **306** to attach the cover **306** to the tip **130** using a threaded fastener. In other embodiments, there are no threaded holes **1010** and fastener holes **1104**, and the end cap **306** is attached to the vane **132** using another securing device.

[0080] The corner seals **100** are accessed for service, in one embodiment, by removing the fasteners **308** from the side of the vane **132** to be accessed. The end cap **306** is removable by grasping the end cap **306** and sliding it in a direction perpendicular to the surface **1012** of the vane **132**. To remove the corner seals, the end cap **306** is removed from both sides of the vane **132**. The corner seals **100** lift out away from the corner **134**, **136**.

[0081] Positioned near the tip **130** on the first face **116** is a pair of ports **1006** that connect the chamber defined by the first face **116** to the space under the trailing seal **100-T**. The second face **118** has a second pair of ports **1006** that connect the chamber defined by the second face **118** to the space under the leading seal **100-L**.

[0082] FIG. **12** illustrates a partial exploded cross-sectional view of one embodiment of the corner seals **100-T**, **100-L** with helical springs **1202**, **1204**. The corner seals **100-T**, **100-L** are biased away from the vane. In the illustrated embodiment, a channel **1212** receives the trailing seal **100-T**. The channel **1212** has a series of posts **1206-T** extending from the bottom of the channel **1212**. Helical springs **1202-T** are positioned on the posts **1206-T** and contact the bottom **1208** of the trailing seal **100-T**. In one embodiment, the posts **1206-T** have a height sufficient to cause the trailing seal **100-T** to bottom out at the fully depressed position of the seal **100-T2**.

[0083] In the illustrated embodiment, the leading seal **100-L** includes a channel **1210**. Opposite the channel **1210** is a series of posts **1206-L** extending from the vane **132**. Helical springs **1202-L** are positioned on the posts **1206-L** and contact the bottom of the channel **1210** in the leading seal **100-T**. In one embodiment, the posts **1206-L** have a height sufficient to cause the trailing seal **100-T** to bottom out at the fully depressed position of the seal **100-L2**.

[0084] The retaining pins, or posts, **1202** are cylindrical. The coil springs **1202** are dimensioned and configured to fit over the diameter of the retaining pins **1202**. The coil springs **1202** apply force against the corner seals **100-T**, **100-L** when the end cap retainer **1102** is attached to the vane **132**.

[0085] FIG. **13** illustrates another embodiment of the corner seals **100-T'**, **100-L'** with wave springs **1302**. In the illustrated embodiment, the seals **100-T'**, **100-L'** are biased with wave springs **1402** that are positioned along the length of the corner seals **100-T'**, **100-L'**. FIG. 13 shows the leading seal **100-L'** with a channel **1210'** configured to receive the wave spring **1302** and the spring seat **1304** protruding from the vane **132**. The wave spring **1302** is a corrugated structure with the size and configuration of the corrugations determining the spring force to be applied by the spring. The illustrated spring seat **1304** extends the length between the opposing retaining posts **1004** on the leading seal **100-L'**. The wave spring **1302** has substantially the same length. In this way the wave spring **1302** exerts an even biasing force to the leading seal **100-L'** across the full length of the leading seal **100-L'**. The trailing seal **100-T'** has a substantially similar configuration as the leading seal **100-L'**. Also visible in the illustrated embodiment are the pair of ports **1006** that connect the chamber defined by the first face **116** to the space under the trailing seal **100-T'**.

[0086] FIG. **14** illustrates a partial plan view of another embodiment of a planetary rotor **106'** showing another embodiment of the seals **100-T''**, **100-L''** and end cap **306'**. FIG. **15** illustrates a partial perspective view of the embodiment of the planetary rotor **106'** illustrated in FIG. 14. FIG. **17** illustrates a partial plan view of the planetary rotor **106'** illustrated in FIG. 14. Although the configuration of this embodiment differs from that of the tip **130-A** illustrated in Figures 3 to 7B, the illustrated embodiment of the tip **130-B** operates in substantially the same way.

[0087] The illustrated embodiment of the tip **130-B** includes a leading seal **100-L**" and a trailing seal **100-T**". In one embodiment, the tip seals **100-L**", **100-T**" are an alloy steel such as 4140 annealed. Such material provides a wearable surface that allows the tip seals **100-L**", **100-T**"to be sacrificial and minimize the wear on the parts that move relative to the seals **100-L**", **100-T**". The seals **100-L**", **100-T**" fit into and are held captive in shaped slots **1408**, **1406**, respectively. Each tip seal **100-T**", **100-L**" has a leaf spring **1412** positioned between the bottom of the shaped slots **1408**, **1406** and the respective tip seal **100-T**", **100-L**". The leading seal **100-L**" projects beyond the tip surface **138** and projects beyond the second surface **118**. The projecting surface of the leading seal **100-L**" has a contour shaped to maintain a sealing connection with the cutout **126** and the lobes **112**. The illustrated embodiment of the trailing seal **100-T**" has an arcuate shape that protrudes beyond the tip surface **138** and the first surface **116**.

[0088] An end cap spring **1414** and an end cap **306'** fit into a cavity **1410** in the planetary rotor **106'**. The illustrated end cap spring **1414** is a washer of spring steel with a twist such that the spring **1414** is non-planar. The end cap **306'** slidably engages the cavity **1410** such that the end cap **306'** is biased away from the planetary rotor **106'**. The planetary rotor **106'** includes slots **1402** that align with the end cap slots **1404** when the end cap **306'** is positioned in the cavity **1410**. The slots **1402**, **1402** receive a seal spring **1418**, such as a wire of spring steel with a wave-shaped configuration, and a seal **1416**. The seal spring **1418** is positioned between the seal **1416** and the bottom of the slots **1402**, **1404**. The seal **1416** is biased away from the face of the planetary rotor **106'** by the seal spring **1418** and the end cap **306'**. In one embodiment, the seal **1416** has a rectangular cross section.

[0089] Shown in phantom are the ports **1006-T**, **1006-L**, which are conduits connecting each surface **116**, **118** to its corresponding slot **1406**, **1408**. When the first face **116** defines a chamber that is pressurized, such as when combustion is occurring, the pressurized fluid enters the ports **1006-T** on the first face **116** and pressurizes the space in the slot **1406**, which causes a force to be applied to bias the trailing seal **100-T**" away from the slot **1406** and tip **130-B**. In this way, when the chamber is pressurized and in the most need for a strong seal, the pressurized fluid aid in increasing the bias force **406** on the trailing seal **100-T''**. The pressurized force **426** is additive to the force contributed by the spring **1412**. The ports **1006-L** operate in a like manner for the leading seal **100-L''**.

[0090] FIG. **16** illustrates a perspective view of the embodiment of the end cap **306'** illustrated in FIG. 14. The end cap **306'** has a cylindrical configuration sized to loosely engage the tip cavity **1410** in the planetary rotor **106'**. The thickness of the end cap **306'** is substantially the same as the depth of the cavity **1410** in the planetary rotor **106'**.

[0091] The outward face of the end cap **306'** has a pair of cap sealing slots **1404** that align with the planetary rotor sealing slots **1402** in the surface of the planetary rotor **106'**. With the end cap **306'** received in the cavity **1410**, the outer surface of the end cap **306'** is substantially flush with the surface of the planetary rotor **106'** and the planetary rotor seals fit into the slots **1402**, **1404** and hold the end cap **306'** in the cavity **1410**. In this way, the end caps **306'** also prevent the tip seals **100-T''**, **100-L''** from sliding out of their respective slots **1406**, **1408**.

[0092] FIG. **18** illustrates a plan view of the embodiment of the trailing tip seal **100-T''** illustrated in FIG. 14. FIG. **19** illustrates a side view of the embodiment of the trailing tip seal **100-T''** illustrated in FIG. 14. The trailing tip seal **100-T''** is elongated with a contact surface **1802** opposite a captive portion **1804**. The contact surface **1802** is parallel to the longitudinal axis of the trailing tip seal **100-T''**. In one embodiment, the contact surface **1802** has an arcuate profile in a plane normal to the longitudinal axis of the trailing tip seal **100-T''**. In one such embodiment, the contact surface **1802** has a partial circular cross section. The captive portion **1804** slidably moves in the slot **1406** between the first surface **116** and the tip surface **138** of the tip **130-B**.

[0093] The captive portion **1804** has a configuration that engages the slot **1406** such that the trailing tip seal **100-T''** is captive in the slot **1406** with limited movement of the contact surface **1802** relative to the planetary rotor **106'**. The captive portion **1804** has a recess **1808** that receives a portion of the wave spring **1302**, which biases the trailing tip seal **100-T''** away from the planetary rotor **106'**. Extending from the captive portion **1804** are a pair of ledges, or shelves, **1806** that engage corresponding surfaces **1704** in the slot

1406. The engagement of the surfaces **1704** by the ledges **1806** defines a limit of outward travel of the trailing tip seal **100-T''** away from the planetary rotor **106'**.

[0094] The captive portion **1804** has a length **1904** that is substantially the same or less than the length of the slot **1406**. Between the captive portion **1804** and the distal ends of the trailing tip seal **100-T''** is a gap **1902** that is substantially equal to the thickness of the end cap **306'**. The trailing tip seal **100-T''** has a surface **1810** that extends from the captive portion **1804** to the distal end of the trailing tip seal **100-T''**. This surface **1810** has an arcuate shape that conforms to the cylindrical perimeter of the end cap **306'**.

[0095] The surface **1810** is positioned such that, in one embodiment, the surface **1810** contacts the cylindrical perimeter of the end cap **306'**, thereby defining one limit of the range of motion of the trailing tip seal **100-T''**. The surface **1810** is positioned such that the surface **1810** does not contact the cylindrical perimeter of the end cap **306'** when the trailing tip seal **100-T''** is at its limit of the range of motion toward the bottom of the slot **1406**. The sides of the recess **1808** engage the bottom of the slot **1406** to define the limit of the range of motion toward the bottom of the slot **1406**. With these features, the inside surface of the end cap **306'** prevents the captive portion **1804** from sliding laterally out of the slot **1406**. Also, the distal end of the trailing tip seal **100-T''** is substantially flush with the outer surface of the planetary rotor **106'**.

[0096] FIG. 19 illustrates a leaf spring **1412** displaced from the captive portion **1804**. The leaf spring **1412** is shown with its two ends positioned to engage the recess **1808** in the trailing tip seal **100-T''**. The leaf spring **1412** has a length that is less than the length of the captive portion **1804** such that the recess **1808** contains the leaf spring **1412** when the spring **1412** is collapsed flat. The medial portion of the leaf spring **1412** engages the inside of the slot **1406**. With this configuration, the spring force from the leaf spring **1414** is distributed to two points on the trailing tip seal **100-T''** and one point on the planetary rotor **106'**, which is more massive than the tip seals **100** and able to receive the spring force without deformation of the planetary rotor **106'**

[0097] FIG. **20** illustrates a plan view of the embodiment of the leading tip seal **100-L''** illustrated in FIG. 14. FIG. **21** illustrates a side view of the embodiment of the leading tip seal **100-L''** illustrated in FIG. 14. The leading tip seal **100-L''** is elongated with a contact surface **2002** opposite a captive portion **2004.** The contact surface **2002** is parallel to the longitudinal axis of the leading tip seal **100-L''**. The contact surface **2002** has a configuration with a leading portion **2012** and a trailing portion **2014.** In one embodiment, the contact surface **2002** has an arcuate profile in a plane normal to the longitudinal axis of the leading tip seal **100-L''**. The leading portion **2012** and the trailing portion **2014** are joined with an arcuate surface. In one embodiment, such arcuate surface has a partial circular profile or cross-section and the leading and trailing portions **2012**, **2014** are slightly convex surfaces in profile or cross-section. The configuration of the contact surface **2002** is such to provide a transition between the surfaces of the internal cavity **124** and the surfaces of the cutouts **126** as the planetary rotor **106'** moves in the rotary engine **102.**

[0098] The leading tip seal **100-L''** slidably moves in the slot **1408** between the second surface **118** and the tip surface **138** of the tip **130-B.** The captive portion **2004** has a configuration that engages the slot **1408** such that the leading tip seal **100-L''** is captive in the slot **1408** with limited movement of the contact surface **2002** relative to the planetary rotor **106'.** The captive portion **2004** has a recess **1808** that receives a portion of the wave spring **1302**, which biases the leading tip seal **100-L''** away from the planetary rotor **106'.** Extending from the captive portion **2004** are a pair of ledges, or shelves, **2006** that engage corresponding surfaces **1714** in the slot **1408.** The engagement of the surfaces **1714** by the ledges **2006** defines a limit of outward travel of the leading tip seal **100-L''** away from the planetary rotor **106'.**

[0099] The captive portion **2004** has a length **2104** that is substantially the same or less than the length of the slot **1408.** Between the captive portion **2004** and the distal ends of the leading tip seal **100-L''** is a gap **2002** that is substantially equal to the thickness of the end cap **306'.** The leading tip seal **100-L''** has a surface **2010** that extends from the captive portion **2004** to the distal end of the leading tip seal **100-L''.** This surface **2010** has an arcuate shape that conforms to the cylindrical perimeter of the end cap **306'.** The surface **2010** is positioned such that the surface **2010** does not contact the cylindrical perimeter of the end cap **306'** when the leading tip seal **100-L''** is at its limit of the range of motion toward the bottom of the slot **1408.** In one embodiment, the surface **2008** on each side of the captive portion **2004** engages corresponding surfaces on the planetary rotor to define the limit of the range of motion toward the bottom of the slot **1408**. With these features, the inside surface of the end cap **306'** and the spring **1412** prevent the captive portion **2004** from sliding laterally out of the slot **1408**. Also, the distal end of the leading tip seal **100-L''** is substantially flush with the outer surface of the planetary rotor **106'**.

[00100] FIG. **22** illustrates a partial plan view of another embodiment of the main rotor **108'** showing one cutout **126'**. The surface of the cutout **126'** has two cylindrical regions **2206**, **2214**. The first cylindrical region **2206** is defined by a first radius **2204** extending from a first center **2202** of the cutout **126'**.

[00101] The second cylindrical region **2214** defines the forward surface **204'** and has a length **2212**. The second cylindrical region **2214** is defined by a second radius **2208** extending from a second center **2210** offset from the first center **2202** of the cutout **126'**. The second center **2210** is defined by the intersection of a first offset **2214** and a second offset **2216** from the center **2218** of the main rotor **108'** with the cutout **126'** positioned as illustrated in Figure 22. The second center **2210** is positioned such that the second cylindrical region **2214** is dimensioned to provide a graduated entry zone, or forward surface, **204'** for the trailing tip seal **100-T''** when it engages the cutout **126'**. The forward surface **204'** allows the tip seals **100-T''**, **100-L''** to engage the cutout **126'** with the tip seals **100-T''**, **100-L''** fully extended and to be gradually moved against the bias of the leaf spring **1412** as the tip seals **100-T''**, **100-L''** engage the first cylindrical region **2206**.

[00102] The second cylindrical region **2214** joins the first cylindrical region **2206** at a tangent defined by a line passing through the first center **2202** and the second center-point **2210**.

[00103] FIG. **23** illustrates a partial plan view of one embodiment of a housing **104** showing the side seal **2306**. FIG. **24** illustrates a perspective view of one embodiment of a housing button seal **2308**. FIG. **25** illustrates a plan view of one embodiment of a spring washer **1414**.

[00104] The housing **104** includes a side surface that engages a rotating plate that supports the movable members **106**, **106'**. The side surface, or face, of the housing **104** has a housing slot that is adjacent to and follows the contour of the lobes **112**. The housing slot receives a spring and a seal **2306** that are similar to the seal spring **1418** and seal **1416** for the planetary rotor **106'**. Three housing seals **2306** are used to seal the periphery of the housing cavity. A housing button **2308** with a pair of button slots **2402** fit into a cavity that intersects the housing slot.

[00105] In the illustrated embodiment, the buttons **2308** joining adjacent seals **2306** are located proximate the midpoint of the lobe **112**. The midpoint of the lobe **112**, for one type of rotary engine, is exposed to a lower pressure than other portions of the lobe **112**. The location of the button **2308** proximate the low pressure region reduces the potential leakage by the gap between the housing seals **2306** that terminate in the button slots **2402**.

[00106] A spring **1414** fits between the button **2308** and the cavity bottom. The spring **1414** has a twist **2502** that renders the spring **1414** non-planar such that the two ends of the spring **1414** apply a spring force to one of the button and the cavity bottom. The spring **1414** biases the button **2308** away from the surface of the housing **104** and provides support to the ends of the housing seals **2306**.

[00107] In operation, the dual tip seals **100** maintain the pressure integrity of the chamber defined by the planetary rotor **106** and the lobes **112** during the compression and combustion cycles for each face **116**, **118** of the rotor **106**. For example, FIG. 1 illustrates the engine **102** with the main rotor **108** rotated a few degrees past top dead center. The first face **116** defines a chamber that is in the combustion cycle. The fuel from the fuel injector **141** is combusting in the chamber and the chamber has a high pressure from the combustion. One distal end of the first face **116** has a trailing seal **100-T** and the opposite distal end of the first face has a leading seal **100-L**. Both seals **100-T**, **100-L** are engaging the surface of the lobe **112**. The seals **100-T**, **100-L** are biased against the surface of the lobe **112** by way of a spring **1202**, **1302**, **1412**. Also, the ports **1006** in the first face **116** transfer a portion of the pressure in the chamber to the space under the seals **100-T**, **100-L**, which further biases the seals **100-T**, **100-L** toward the surface of the lobe **112**. The bias force **406** from the springs **1202**, **1302**, **1412** and the combustion pressure communicating through the ports **1006** ensures that the seals **100-T**, **100-L** are forced against the surface of the lobe **112** with sufficient force to maintain a seal of the combustion chamber.

[00108] The planetary rotor **106** orbits clockwise when viewed as shown in the figures. As the combustion cycle continues, the planetary rotor **106** orbits into a position such as illustrated in FIG. 2A. The leading seal **100-L** engages the surface of the cutout **126**, first encountering the forward surface **204'**.

[00109] From the combustion cycle, the planetary rotor **106** continues its orbit until the exhaust cycle begins. Continuing along its orbit, the exhaust cycle transitions into the intact cycle for the first surface **116**. For both the exhaust and intake cycles, the pressure in the chamber is reduced from that of the combustion cycle. The primary bias force **406**, **412** is from the spring **1202**, **1302**, **1412**. As the first surface **116** transitions into the exhaust cycle, the pressure built up under the seals **100-T**, **100-L** during the compression and combustion cycles likewise exhausts through the ports **1006**, thereby reducing the pressure bias force **426**, **422**.

[00110] The compression cycle begins after the intake cycle. At the beginning of the compression cycle, the leading seal **100-L** is engaging the cutout **126** and the trailing seal **100-T** is engaging the lobe **112**. As the pressure builds up during the compression cycle, the pressure is communicated through the ports **1006** and the pressure bias force **426**, **422** increases, thereby increasing the bias force **406**, **412** to main pressure integrity of the chamber.

[00111] The corner seals **100** for a rotary engine **102** includes various functions. The function of sealing the interface between the tip **130** of a rotor **108** and the lobe **112** of a rotary engine **102** is implemented, in one embodiment, by a leading corner seal **100-L** and a trailing corner seal **100-T** being biased to protrude above the tip surface **138**. The corner seals **100** are biased such that gaps created by thermal expansion and manufacturing tolerances are filled. In this way, a compliant and durable seal is provided during operation of the rotary engine **102**.

[00112] The function of sealing the interface between a tip **130** having dual corner seals **100** and the lobe **112** of a rotary engine **102** is implemented, in one embodiment, by an asymmetrical lobe **112** configuration that provides a smooth transition as the tip **130** traverses the lobe **112**.

[00113] The function of minimizing components that need to be replaced during normal use is implemented, in one embodiment, by removable corner seals **100**. The corner seals **100** are certain to deteriorate during normal use. A separable corner seal **100** provides a lower cost way to replace the corner seals **100** than the alternative of replacing the rotor **108**.

[00114] From the foregoing description, it will be recognized by those skilled in the art that biased corner seals **100** and an asymmetrical lobe **112** for a rotary engine **102** have been provided. Where the rotary engine **102** includes an internal cavity, a main rotor, and a plurality of planetary rotors **106**, the corner seals **100** are disposed on the planetary rotors **106**. The planetary rotors **106** include a plurality of vanes **132**. The vanes **132** include two surfaces: the first surface **116** and the second surface **118**. The two surfaces **116**, **118** terminate at a tip surface **138** forming two corners **134**, **136**. The leading corner seal **100-L** is disposed at the leading corner **136**. The trailing corner seal **100-T** is disposed at the trailing corner **134**.

[00115] The internal cavity includes a plurality of lobes **112**. The main rotor **108** rotates about a main shaft **110** within the lobes **112**. The planetary rotors **106** orbit the main shaft **110**. The planetary rotors **106** are located between the lobes **112** and a cutout **126** in the main rotor **108**. The tips **130** of the vanes **132** slide about the surfaces of the lobes **112** and the cutout **126**. The corner seals **100** are biased away from the corners **134**, **136** of the vane **132**. Being biased, the corner seals **100** apply force against lobes **112** and the cutout **126**. The gaps that exist due to thermal expansion and/or manufacturing tolerances are filled by the biased corner seals **100** such that a compliant and durable seal exists along the sealing surfaces.

[00116] The asymmetrical lobe **112'** provides an improved transition zone **802**. The transition zone **802** is where the two corner seals **100-L**, **100-T** alternate making contact with the lobe **112**. While the planetary rotor **106** orbits the main shaft **110**, the tips **130** of the vanes **132** pass over the lobe **112**. The lobe **112** has three zones, the trailing zone **804**, the leading zone **806**, and the transition zone **802**. In the trailing zone **804**, the trailing corner seal **100-T** makes a sealing connection with the surface of the lobe **112**. In the leading zone **806**, the leading corner seal **100-L**. makes a sealing connection with the surface of the lobe **112**. Where the main rotor **108** turns clockwise **122**, the corner seals

100 alternate from the trailing corner seal **100-T** to the leading corner seal **100-L** in the transition zone **802**. The asymmetrical lobe **112'** provides a gradual transition such that a sealing connection is maintained during the transition.

[00117] While the present invention has been illustrated by description of several embodiments and while the illustrative embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is therefore not limited to the specific details, representative apparatus and methods, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of applicant's general inventive concept.

CLAIMS

What is claimed is:

1. An apparatus for sealing a connection between a moving member and a housing of an internal combustion engine, the moving member having a tip with a leading edge and a trailing edge, said apparatus comprising:

a first seal having a first length along a first longitudinal axis, said first seal having a first captive portion with a first captive length, said first captive portion configured to slideably engage a first slot in the leading edge of the moving member in a direction perpendicular to said first longitudinal axis, said first seal having a first contact surface, said first contact surface being parallel with said first longitudinal axis, said first contact surface having an arcuate profile in a plane normal to said first longitudinal axis, said first contact surface configured to slidingly engage a surface that is parallel to said first longitudinal axis, said first seal configured to be biased away from said first slot; and

a second seal having a second length along a second longitudinal axis, said second seal having a second captive portion with a second captive length, said second captive portion configured to slideably engage a second slot in the trailing edge of the moving member in a direction perpendicular to said second longitudinal axis, said second seal having a second contact surface, said second contact surface being parallel with said second longitudinal axis, said second contact surface having an arcuate profile in a plane normal to said second longitudinal axis, said second contact surface configured to slidingly engage said surface that is parallel to said second longitudinal axis, and said second seal configured to be biased away from said second slot.

2. The apparatus of Claim 1 further including said movable member and a main rotor, said movable member being a planetary rotor configured to orbit around an axis of rotation of said main rotor with said movable member inside a cutout in said main rotor, said first and second contact surfaces of said first and second seals, respectively, engaging a surface of said cutout to form a seal between said surface and said movable member.

3. The apparatus of Claim 2 further including a first spring disposed between said first captive portion and a bottom of said first slot wherein said first spring biases said first seal away from the movable member, and further including a second spring disposed between said second captive portion and a bottom of said second slot wherein said second spring biases said second seal away from the movable member.

4. The apparatus of Claim 3 wherein said first spring and said second spring are each a wave spring.

5. The apparatus of Claim 3 wherein said first spring and said second spring are each a leaf spring.

6. The apparatus according to one of Claims 2-5 wherein said first captive portion is restrained from being removed from said first slot in the movable member in a direction normal to said first longitudinal axis, and said second captive portion is restrained from being removed from said second slot in the movable member in a direction normal to said second longitudinal axis.

7. The apparatus according to one of Claims 2-6 wherein said cutout is defined by a first cylindrical region and a second cylindrical region, said second cylindrical region has a diameter greater than a diameter of said first cylindrical region, said second cylindrical region extends from one edge of said cutout to said first cylindrical region, wherein said first and second seals enter said cutout proximate said second cylindrical region and each one of said first and second seals is gradually moved against a bias as said first and second seals engage said first cylindrical region.

8. The apparatus according to one of Claims 2-7 further including said housing, said housing defining a plurality of lobes, each one of said plurality of lobes being asymmetrical with a lobe surface defining a trailing zone, a transition zone, and a leading zone, said trailing zone having a curvature allowing said second contact surface to engage said lobe surface with said first contact surface not engaging said lobe surface when said first seal and said second seal are

proximate said trailing zone, said transition zone having a curvature allowing said first and second contact surfaces to engage said lobe surface when said first seal and said second seal are proximate said transition zone, and said leading zone having a curvature allowing said first contact surface to engage said lobe surface with said second contact surface not engaging said lobe surface when said first seal and said second seal are proximate said leading zone.

9. The apparatus according to one of Claims 2-8 further including a first conduit with fluid communication between said first slot and a first surface of said movable member that is proximate said first slot whereby a fluid pressure applied to said first surface passes through said first conduit and pressurizes a space between said first slot and said first captive portion, thereby biasing said first seal away from said first slot.

10. The apparatus of Claim 9 further including a second conduit with fluid communication between said second slot and a second surface of said movable member that is proximate said second slot.

11. The apparatus according to one of Claims 2-10 wherein said first contact surface includes a leading portion and a trailing portion joined with a surface having said arcuate profile.

12. The apparatus of Claim 11 wherein said leading portion and said trailing portion have a convex profile in said plane normal to said first longitudinal axis.

13. The apparatus according to one of Claims 2-12 wherein said arcuate profile of said second contact surface is a partial circular profile.

14. The apparatus according to one of Claims 2-13 further including

a first end cap having a first inside surface configured to be proximate a first distal end of said first captive portion and a first distal end of said second captive portion, said first inside surface proximate a first side of the moving member, and said first end cap is configured to keep said first captive portion of said first seal and said second captive portion of said second seal from sliding longitudinally out of said first and second slots, respectively; and

a second end cap having a second inside surface configured to be proximate a second distal end of said first captive portion and a second distal end of said second captive portion, said second inside surface proximate a second side of the moving member, and said second end cap is configured to keep said first captive portion of said first seal and said second captive portion of said second seal from sliding longitudinally out of said first and second slots, respectively.

15. The apparatus of Claim 14 wherein said first end cap and said second end cap are each secured to the moving member with at least one fastener.

16. The apparatus of Claim 14 wherein said first end cap and said second end cap are each configured received in a recess in said first and second side of the moving member, respectively.

17. The apparatus of Claim 14 further including a first spring disposed between said first inside surface of said first end cap and said first side of the moving member wherein said first end cap is biased away from the moving member, and a second spring disposed between said second inside surface of said second end cap and said second side of the moving member wherein said second end cap is biased away from the moving member.

18. The apparatus of Claim 14 further including a third seal configured to fit into a third slot located on said first side of the moving member, a distal end of said third seal engaging a first cap slot on said first end cap, said third seal biased away from said first side of the moving member, and further including a fourth seal configured to fit into a fourth slot located on said first side of the moving member, a distal end of said fourth seal engaging a second cap slot on said first end cap, said fourth seal biased away from said first side of the moving member.

19. The apparatus according to one of Claims 2-18 further including said housing and a plurality of side seals, said housing having a side surface configured to be proximate a rotating plate, said housing defining a plurality of lobes, said side surface having a housing slot proximate said plurality of lobes, said housing slot dimensioned and configured to receive said plurality of side seals biased away from said housing, said side surface having at least one recess sized to receive a button with a sliding engagement, and said button biased away from said housing, said button having at least one button slot sized to receive a distal end of one of said side seals.

20. The apparatus of Claim 19 wherein said button is biased away from said housing by a spring washer disposed between said button and a bottom of said recess in said housing.

21. An apparatus for sealing in an internal combustion engine, said apparatus comprising:

a rotor having a vane with a first surface defining a portion of a first chamber in the engine and a second surface defining a portion of a second chamber in the engine wherein each one of said first and second chambers is independently exposed to a compression cycle and a combustion cycle, said rotor having a tip joining said first surface and said second surface, said tip having a first corner defining a first slot proximate said first surface, and said tip having a second corner defining a second slot proximate said second surface;

a first seal having a first length along a first longitudinal axis, said first seal having a first captive portion with a first captive length, said first captive portion configured to engage said first slot in said first corner, said first seal having a first contact surface, said first contact surface being parallel with said first longitudinal axis, said first contact surface having an arcuate profile in a plane normal to said first longitudinal axis;

a first spring disposed between said first captive portion and a bottom of said first slot wherein said first spring biases said first seal away from said rotor;

a second seal having a second length along a second longitudinal axis, said second seal having a second captive portion with a second captive length, said second captive portion configured to engage said second slot in said second corner, said second seal having a second contact surface, said second contact surface being parallel with said second longitudinal axis, said second contact surface having an arcuate profile in a plane normal to said second longitudinal axis; and

a second spring disposed between said second captive portion and a bottom of said second slot wherein said second spring biases said second seal away from said rotor.

22. The apparatus of Claim 21 further including a first conduit between said first surface of said rotor and said bottom of said first slot whereby a pressure applied to said first surface passes through said first conduit and pressurizes a space between said bottom of said first slot and said first captive portion, thereby biasing said first seal away from said rotor.

23. The apparatus of Claim 22 further including a second conduit between said second surface of said rotor and said bottom of said second slot whereby a pressure applied to said second surface passes through said second conduit and pressurizes a space between said bottom of said second slot and said second captive portion, thereby biasing said second seal away from said rotor.

24. The apparatus of Claim 21 further including a main rotor having a cutout, said rotor configured to orbit about an axis of rotation of said main rotor with said rotor inside said cutout.

25. The apparatus of Claim 24 wherein said cutout is defined by a first cylindrical region and a second cylindrical region, said second cylindrical region having a second diameter greater than a first diameter of said first cylindrical region, said second cylindrical region extending from one edge of said cutout to said first cylindrical region, wherein said first and second seals enter said cutout proximate said second cylindrical region and each one of said first and second seals is gradually moved against a bias toward said rotor as said first and second seals engage said first cylindrical region.

26. The apparatus of Claim 21 further including a housing, said housing defining a cavity containing said rotor, said cavity defining a plurality of lobes, each one of said plurality of lobes being asymmetrical with a lobe surface defining a trailing zone, a transition zone, and a leading zone, said trailing zone having a curvature allowing said second contact surface to engage said lobe surface with said first contact surface not engaging said lobe surface when said first seal and said second seal are proximate said trailing zone, said transition zone having a curvature allowing said first and second contact surfaces to engage said lobe surface when said first seal and said second seal are proximate said transition zone, and said leading zone having a curvature allowing said first contact surface to engage said lobe surface with said second contact surface not engaging said lobe surface said first seal and said second seal are proximate said leading zone.

27. The apparatus of Claim 21 wherein said first spring and said second spring are each a wave spring.

28. The apparatus of Claim 21 wherein said first spring and said second spring are each a leaf spring.

29. The apparatus of Claim 21 wherein said first captive portion is restrained from being removed from said first slot in a direction normal to said first longitudinal axis, and said second captive portion is restrained from being removed from said second slot in a direction normal to said second longitudinal axis.

30. An apparatus for making a sealing connection with chambers within a rotary engine, said apparatus comprising:

a rotor with a plurality of tips, each tip having a leading edge seal and a trailing edge seal, the leading edge seal being biased away from the tip, the leading edge seal being captive to tip, the trailing edge seal being biased away from the tip, and the trailing edge seal being captive to tip.

31. The apparatus of Claim 30 wherein said trailing edge seal is a partial cylinder that extends along a trailing edge of the tip.

32. The apparatus of Claim 30 wherein said leading edge seal extends along and above a portion of the tip bounded by the leading and trailing edges, and the leading edge seal extends along and protrudes from the face of the rotor.

33. The apparatus of Claim 30 wherein said seals have a captive portion that engages corresponding slots in the rotor, the captive portions are configured to be held captive in the corresponding slots.

34. The apparatus of Claim 30 wherein an end cap is positioned in a cavity in a face of the rotor. The end cap is positioned proximate the tip and blocks the captive portions from sliding out of the corresponding slots. The end cap is biased away from the rotor by a spring. The end cap includes a pair of seal slots that are configured to receive the distal ends of the side seals of the rotor and corresponding springs that bias the seals away from the rotor.

35. The apparatus of Claim 30 wherein said housing of the rotary engine includes a plurality of slots for the side seals positioned proximate the cavity for the rotors. The slots each receive a seal spring and a side seal. The housing also includes a cavity located between adjacent slots. The cavities are dimensioned to slideably receive a button that has a pair of button slots configured to receive the distal ends of the corresponding side seals. The button is biased away from the housing. A spring is positioned between the button and the bottom of the cavity.

36. An apparatus for sealing in an internal combustion engine, said apparatus comprising:

a housing having a lobe defining a cavity in said housing;

a rotor within said cavity in said housing, said rotor having a pair of vanes with a rotor surface extending therebetween, said rotor surface defining a portion of a chamber in said housing, said rotor surface having a first distal end and an opposite distal end, said rotor having a first slot proximate said first distal end, said rotor having a second slot proximate said opposite distal end;

a first seal having a first length along a first longitudinal axis, said first seal having a first captive portion, said first captive portion slideably engaging said first slot in a direction perpendicular to said first longitudinal axis, said first seal having a first contact surface, said first contact surface being parallel with said first longitudinal axis, said first contact surface having an arcuate profile in a plane normal to said first longitudinal axis;

a first spring disposed between said first captive portion and a bottom of said first slot wherein said first spring biases said first seal away from said rotor;

a first conduit between said rotor surface proximate said first distal end and said first slot whereby a pressure proximate said rotor surface is communicated to said bottom of said first slot;

a second seal having a second length along a second longitudinal axis, said second seal having a second captive portion, said second captive portion slideably engaging said second slot in a direction perpendicular to said second longitudinal axis, said second seal having a second contact surface, said second contact surface being parallel with said second longitudinal axis, said second contact surface having an arcuate profile in a plane normal to said second longitudinal axis;

a second spring disposed between said second captive portion and said second slot wherein said second spring biases said second seal away from said rotor; and

a second conduit between said rotor surface proximate said second distal end and a bottom of said second slot whereby said pressure proximate said rotor surface is communicated to said bottom of said second slot;

wherein said rotor surface progressively cycles through an intake cycle, a compression cycle, a combustion cycle, and an exhaust cycle with said first and second seals providing a pressure boundary at said first and opposite distal ends of said rotor surface, and wherein during said compression cycle and said combustion cycle said pressure in said chamber biases said first and second seals away from said rotor.

37. The apparatus of Claim 36 further including a main rotor having a cutout, said rotor configured to orbit about an axis of rotation of said main rotor with said rotor inside said cutout.

38. The apparatus of Claim 37 wherein said cutout is defined by a first cylindrical region and a second cylindrical region, said second cylindrical region having a second diameter greater than a first diameter of said first cylindrical region, said second cylindrical region extending from one edge of said cutout to said first cylindrical region, wherein said first and second seals enter said cutout proximate said second cylindrical region and each one of said first and second seals is gradually moved against a bias toward said rotor as said first and second seals engage said first cylindrical region.

39. The apparatus of Claim 36 wherein said lobe is asymmetrical with a lobe surface defining a trailing zone, a transition zone, and a leading zone, said trailing zone having a curvature allowing said second contact surface to engage said lobe surface when said second seal is proximate said trailing zone, said transition zone having a curvature allowing said first contact surface to engage said lobe surface when said first seal is proximate said transition zone, said transition zone having a curvature allowing said second contact surface to engage said lobe surface when said second seal is proximate said transition zone, and said leading zone having a curvature allowing said first contact surface to engage said lobe surface when said first seal is proximate said leading zone.

40. The apparatus of Claim 36 wherein said first captive portion of said first seal is restrained from being removed from said first slot in a direction normal to said first longitudinal axis, and said second captive portion of said second seal is restrained from being removed from said second slot in a direction normal to said second longitudinal axis.

41. The apparatus of Claim 40 wherein said first captive portion has a first ledge configured to engage a corresponding first surface in said first slot whereby said first ledge engaging said corresponding first surface holds captive said first seal, and said second captive portion has a second ledge configured to engage a corresponding second surface in said first slot whereby said second ledge engaging said corresponding second surface holds captive said second seal.

42. The apparatus of Claim 36 wherein said each one of said pair of vanes has a tip proximate a corresponding one of said first distal end and said opposite distal end of said rotor surface, each one of said tips having a substantially flat surface, said first seal projecting at approximately a forty-five degree angle relative to said flat surface proximate said first seal, and said second seal projecting at approximately a forty-two degree angle relative to said flat surface proximate said second seal.

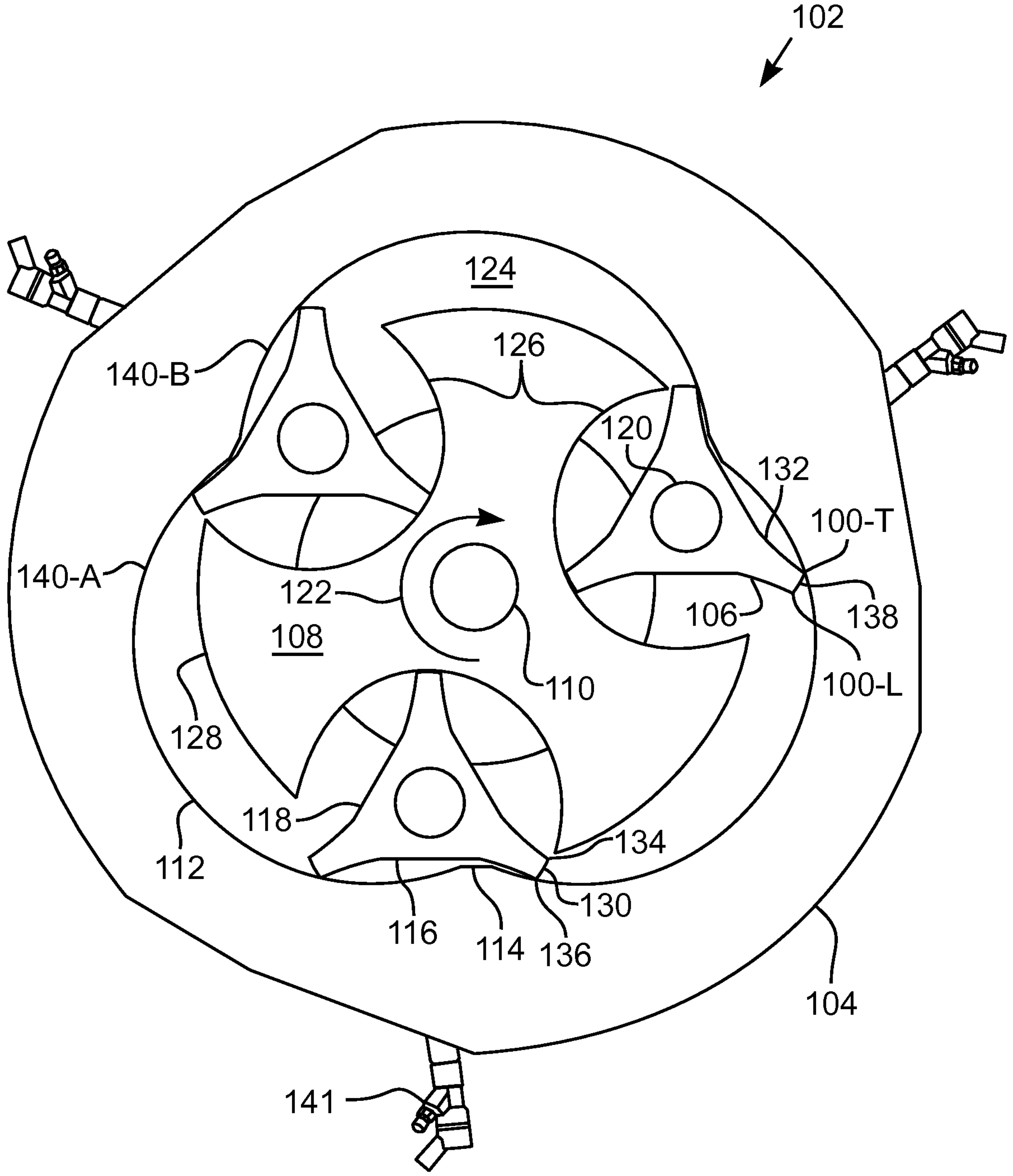

102
124
126
140-B
120
132
100-T
140-A
122
106
138
108
110
100-L
128
118
134
112
130
116
114
136
104
141

Fig. 1

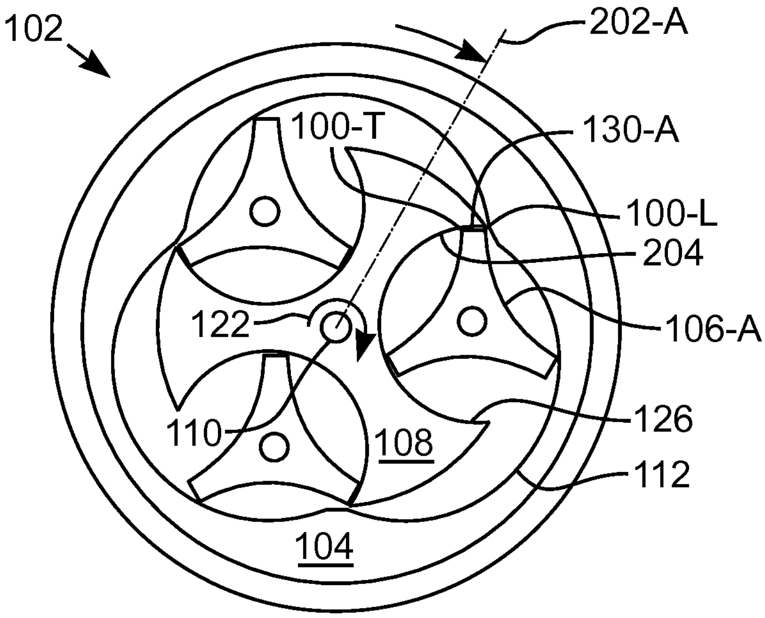


Fig. 2A

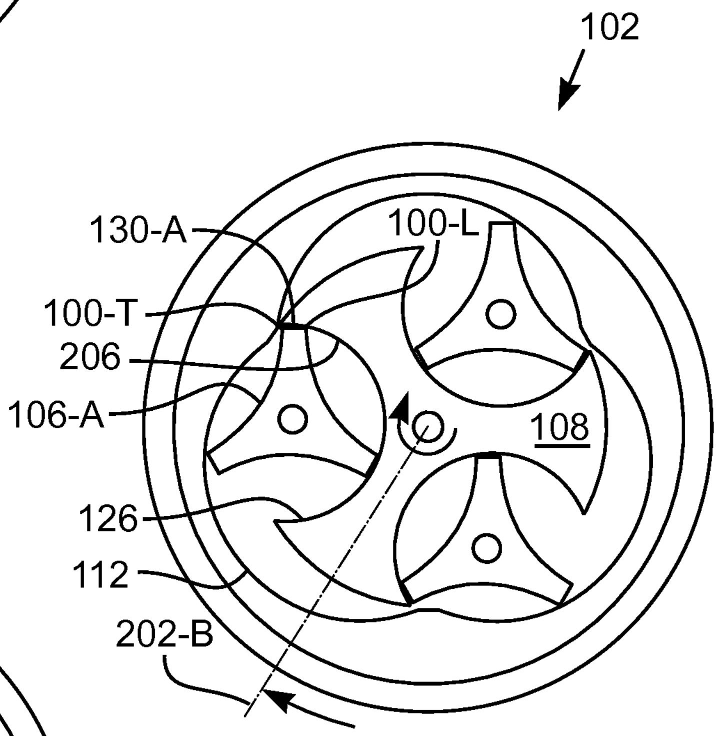


Fig. 2B

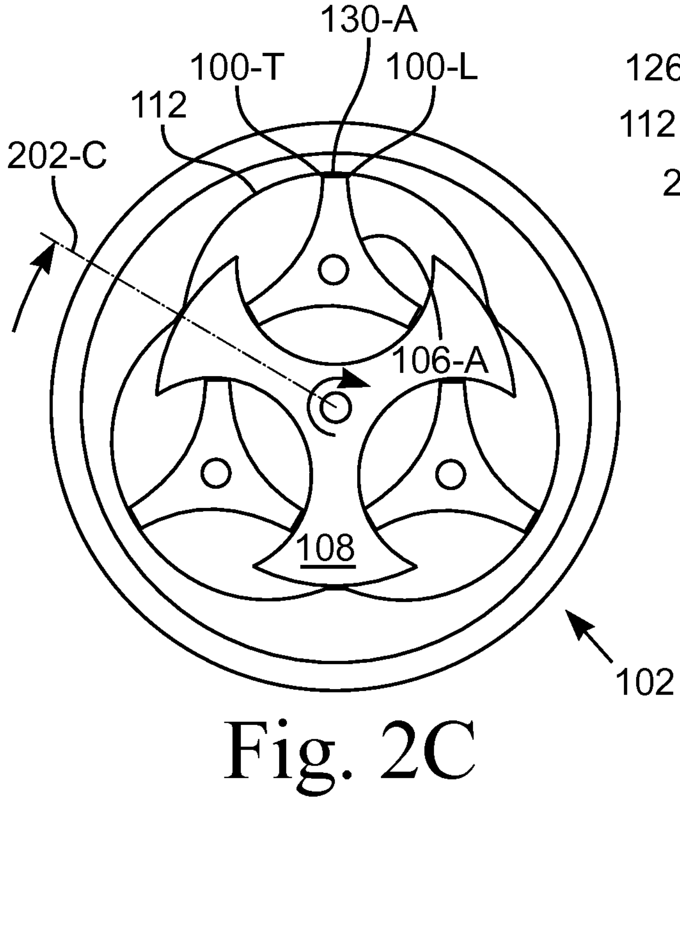


Fig. 2C

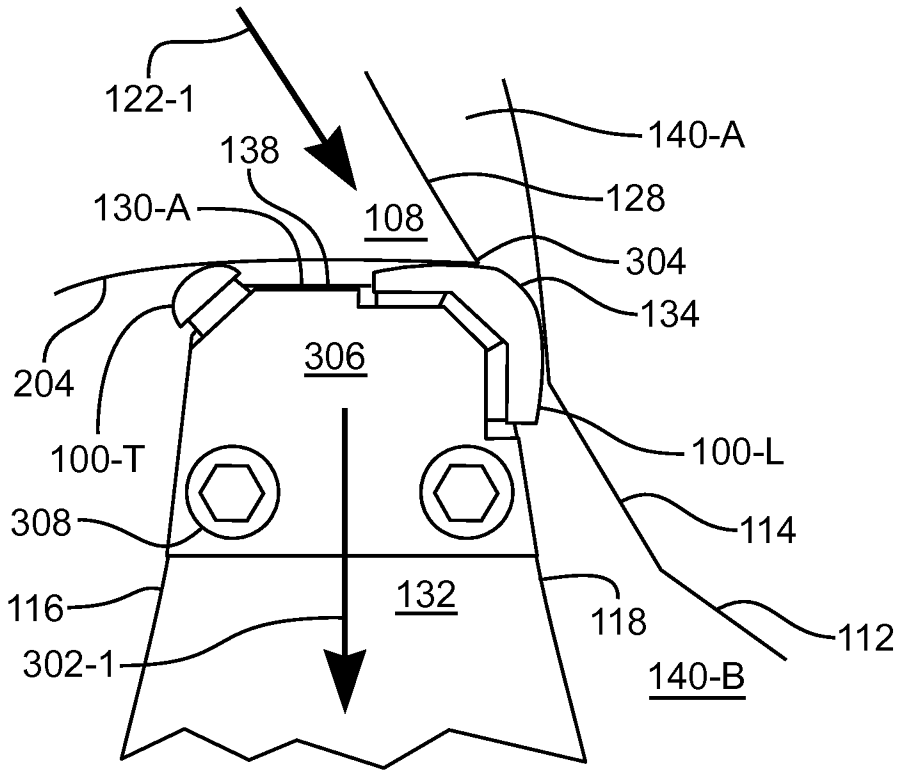
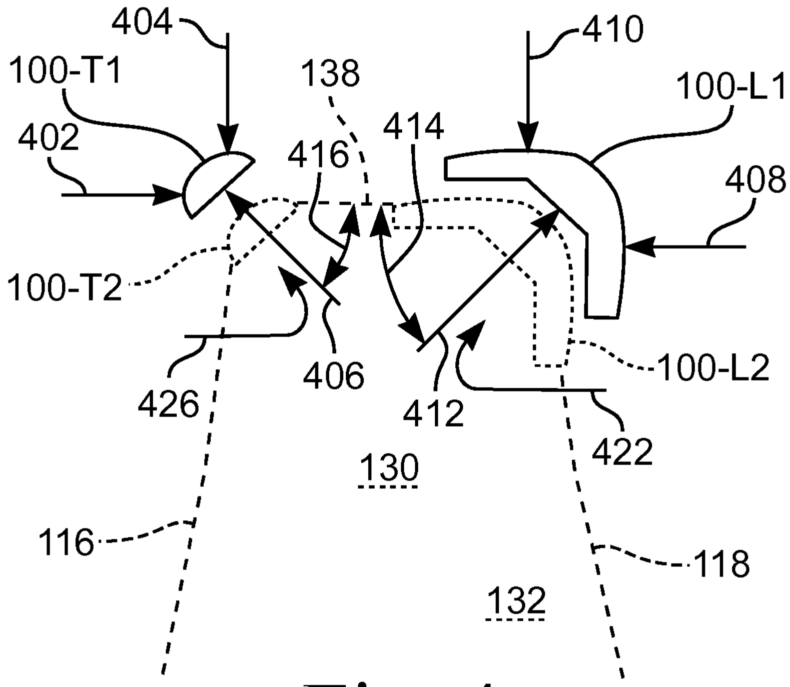

122-1
138
130-A
108
140-A
128
304
134
204
306
100-T
100-L
308
114
116
132
118
112
302-1
140-B

Fig. 3


404
410
100-T1
138
414
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416
408
100-T2
426
406
412
100-L2
422
130
116
118
132

Fig. 4

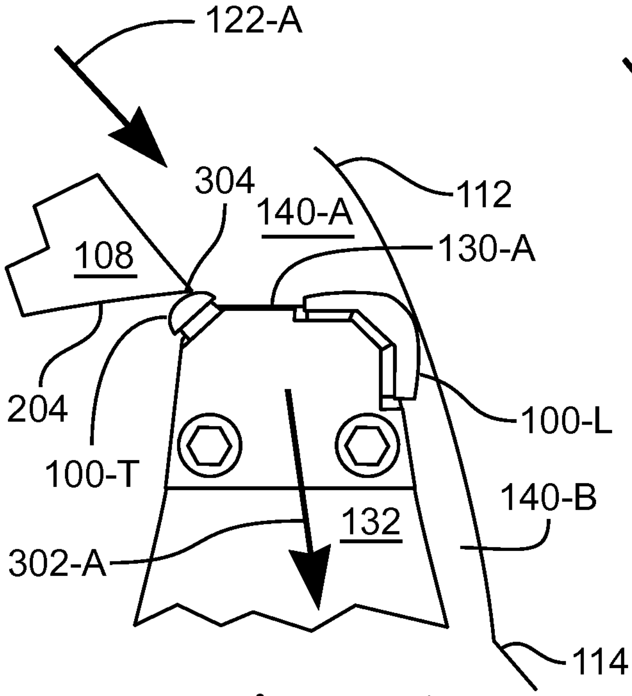


Fig. 5A

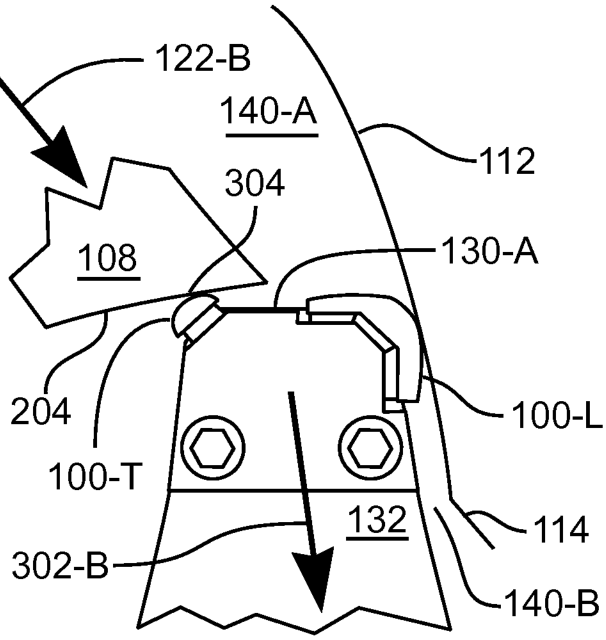


Fig. 5B

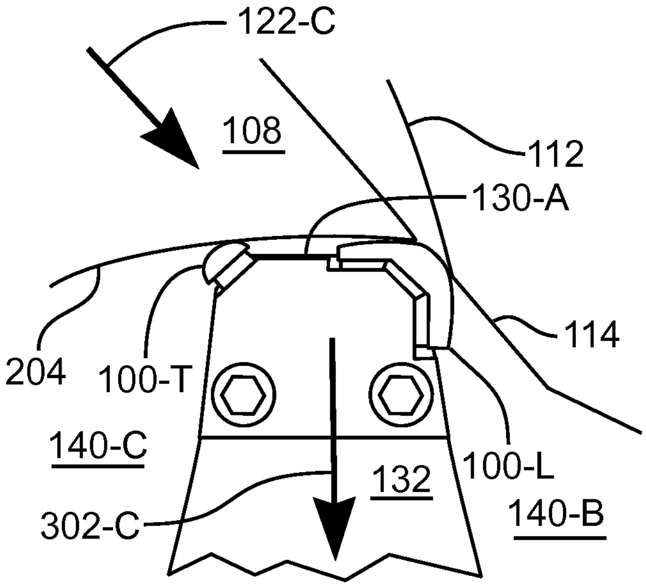


Fig. 5C

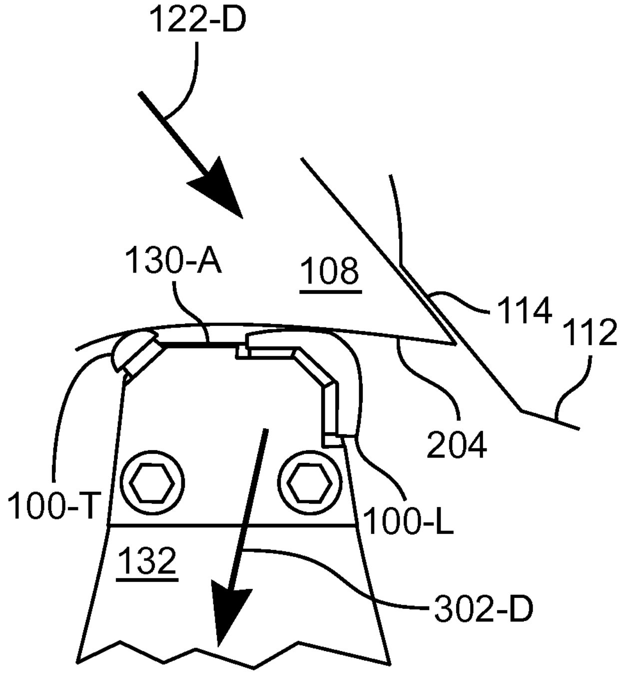


Fig. 5D

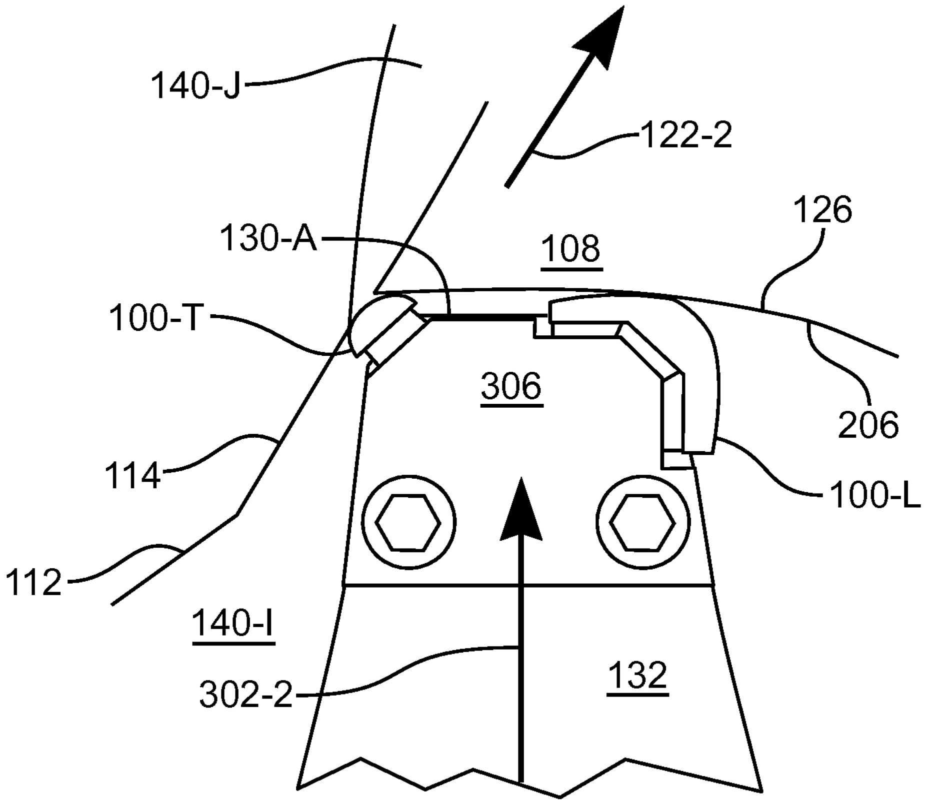


Fig. 6

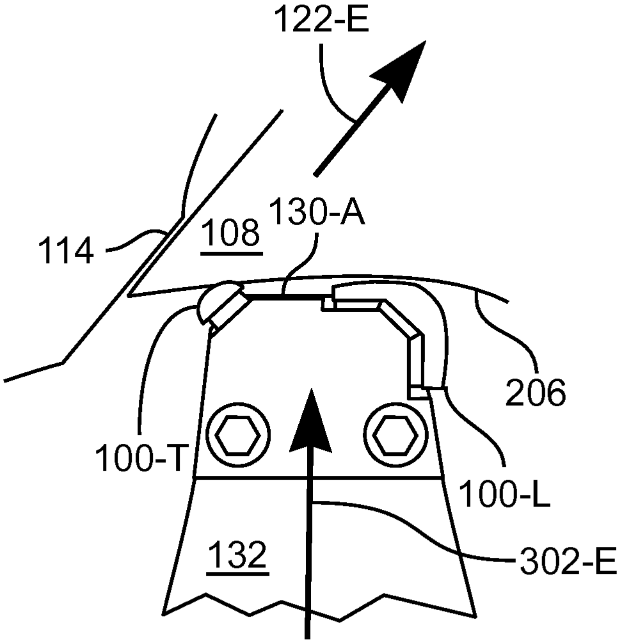


Fig. 7A

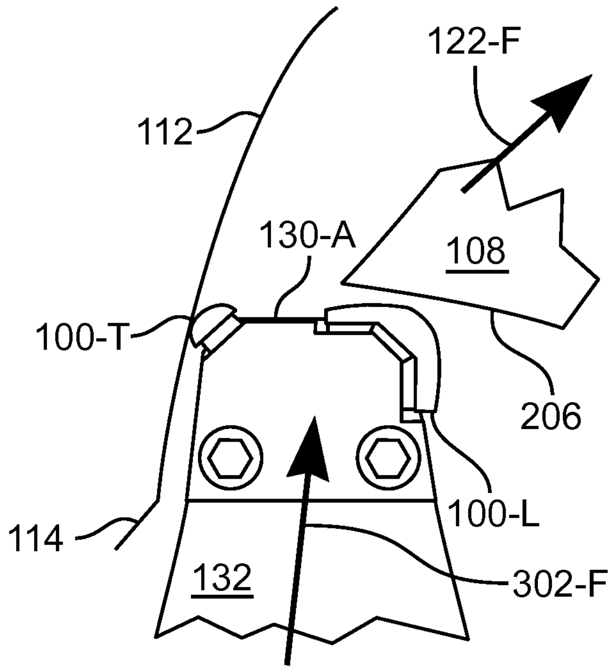
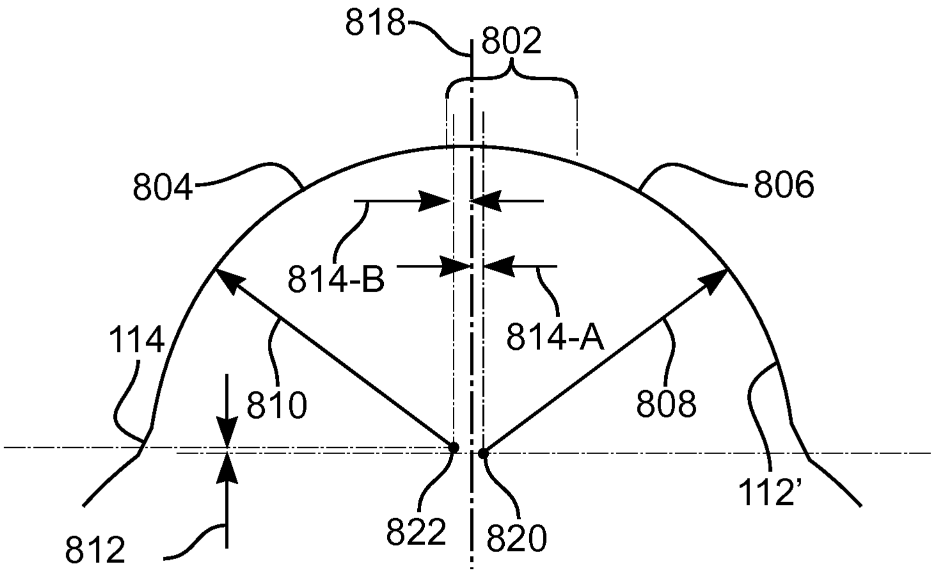


Fig. 7B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814-A
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808
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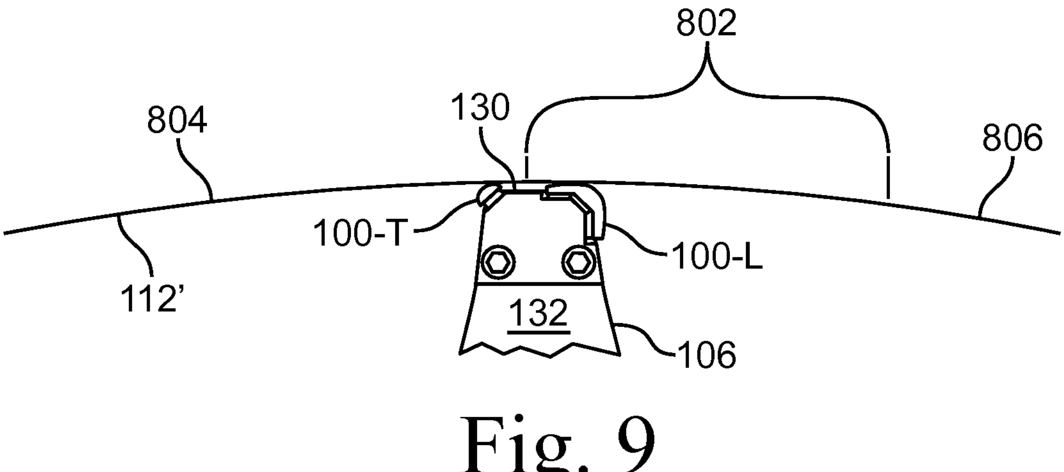
822
820
112'

Fig. 8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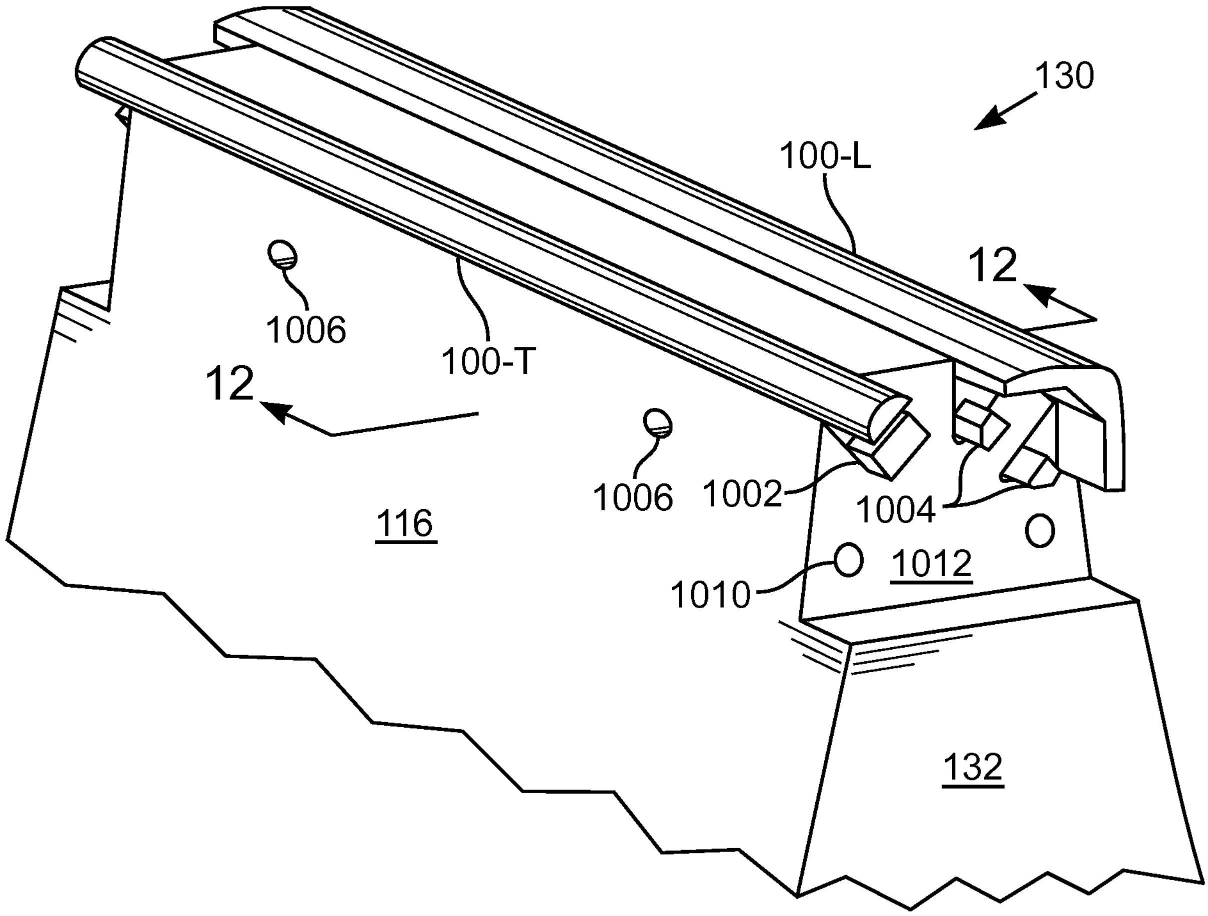
804
806
100-T
100-L
112'
132
106

Fig. 9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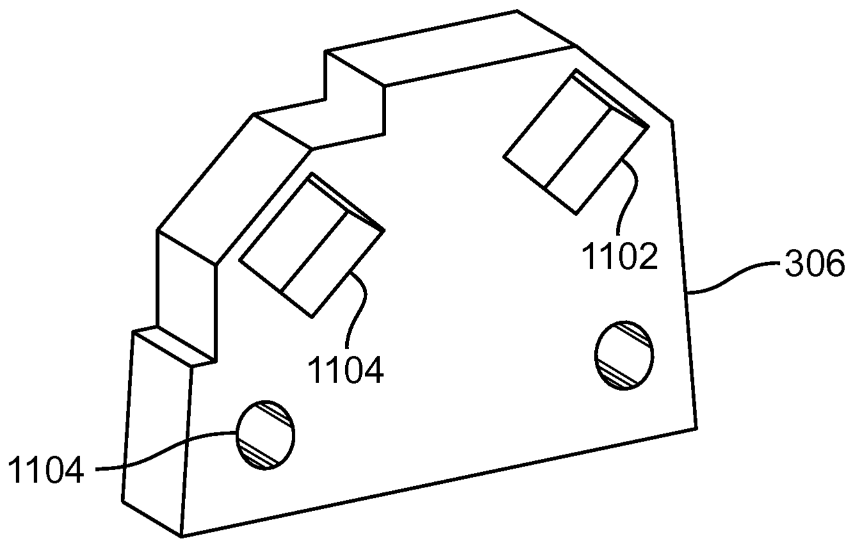
1012
132

Fig. 10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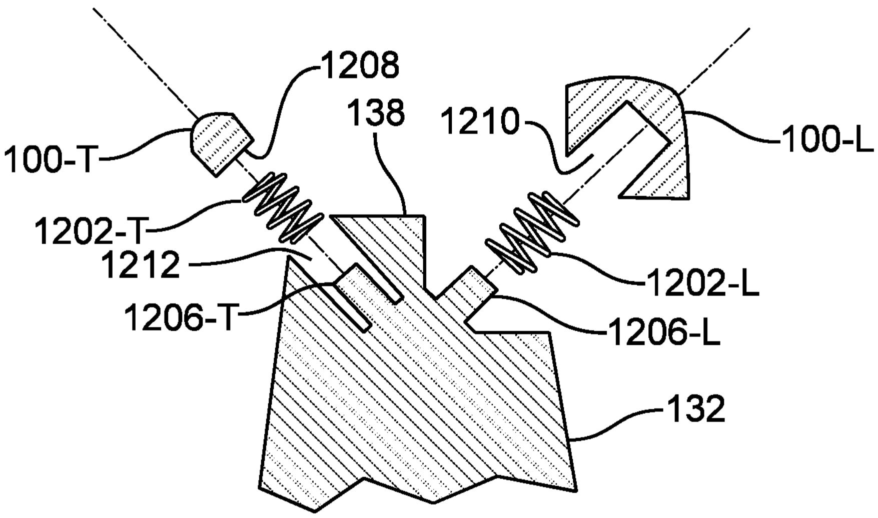
1104
1104

Fig. 11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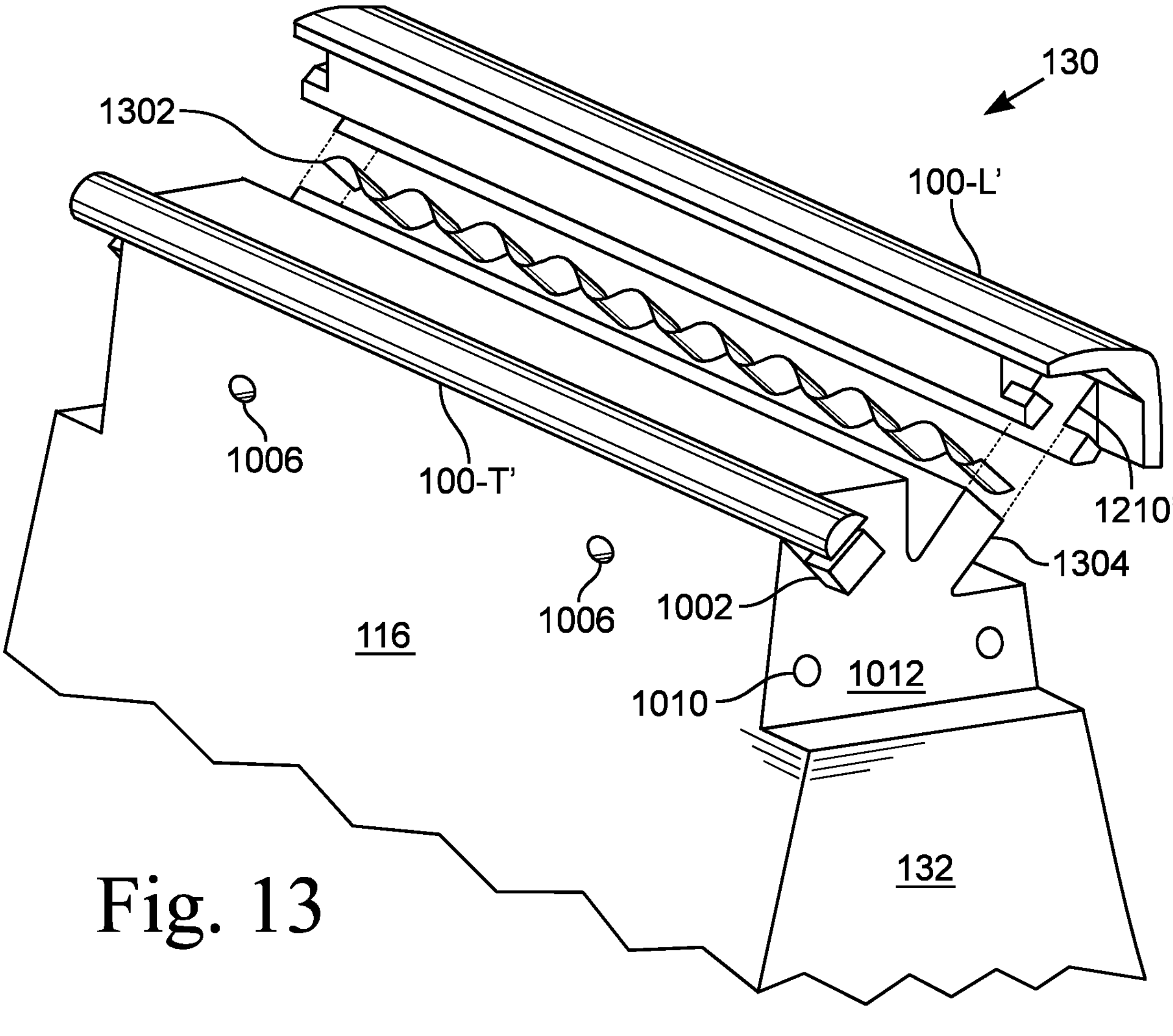
1202-L
1206-T
1206-L
132

Fig. 12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100-T'
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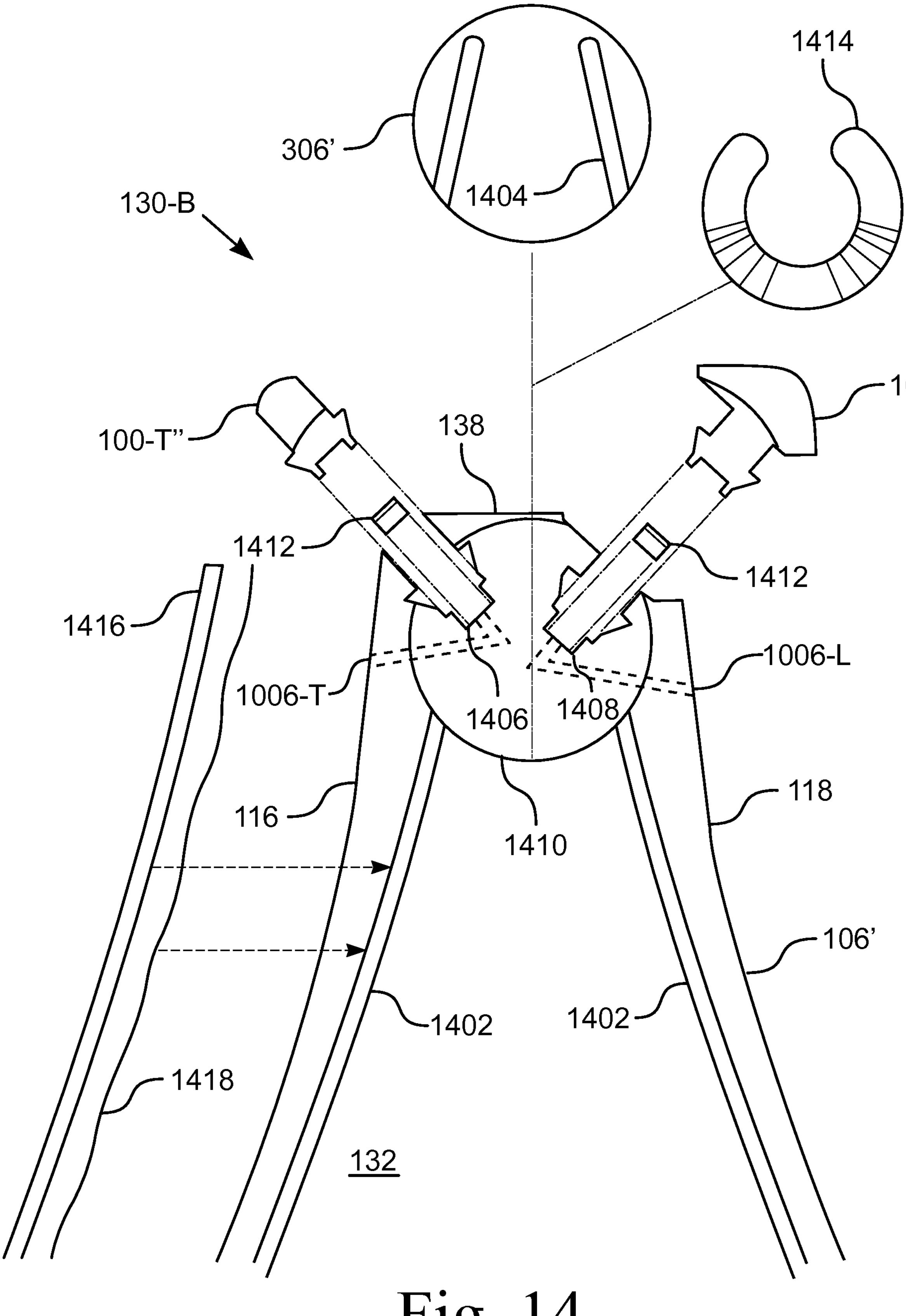
1304
1002
1006
116
1012
1010
132

Fig. 13



1414
306'
1404
130-B
100-L"
100-T"
138
1412
1412
1416
1006-L
1006-T
1406
1408
116
1410
118
106'
1402
1402
1418
132

Fig. 14

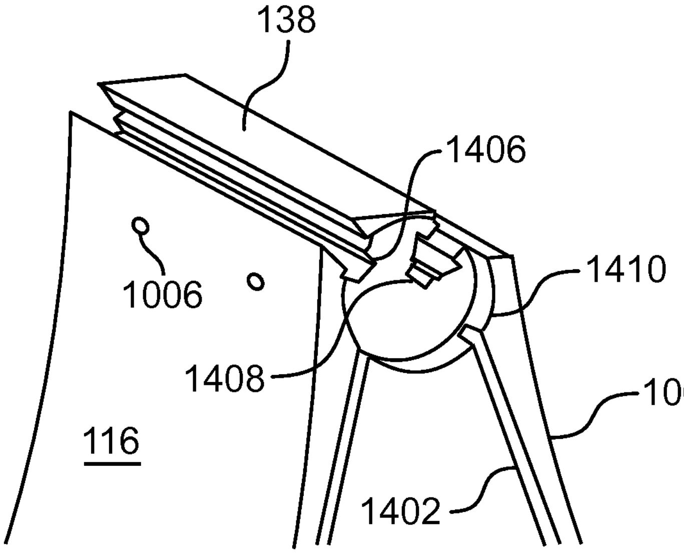


Fig. 15

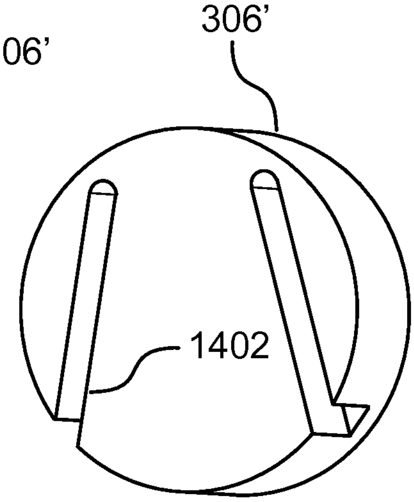


Fig. 16

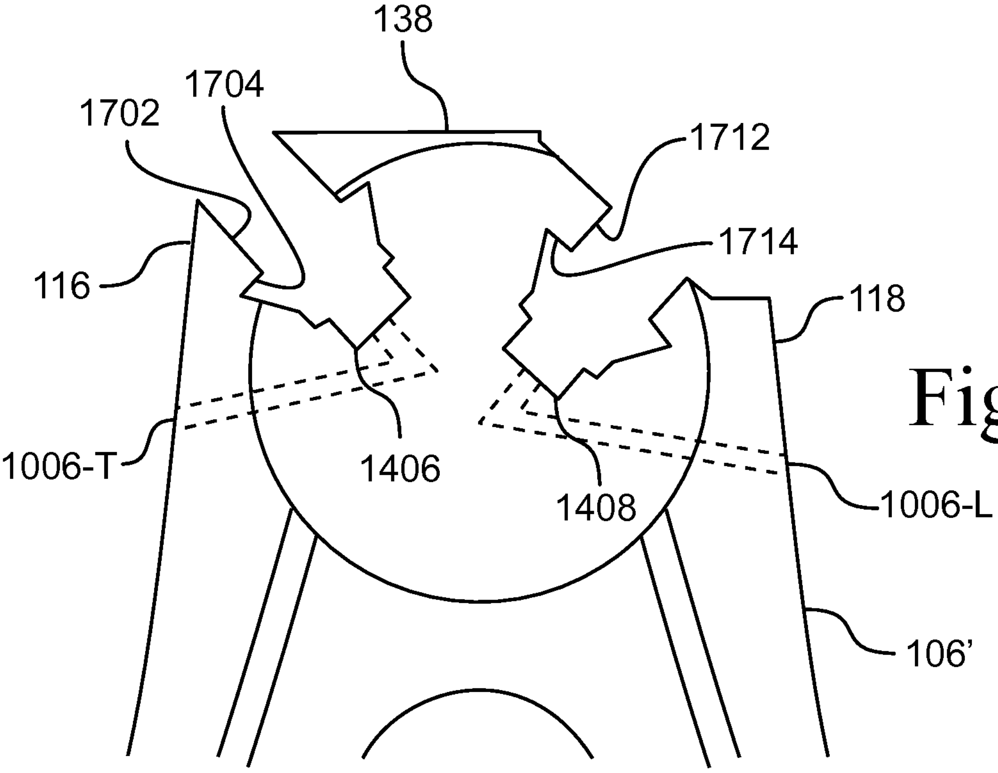


Fig. 17

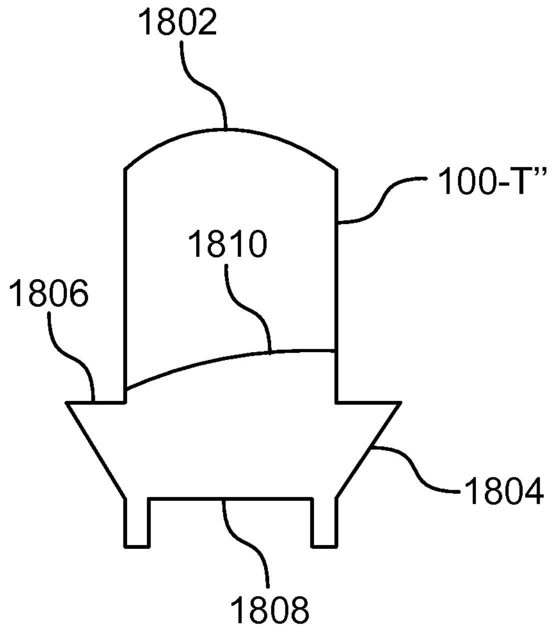


Fig. 18

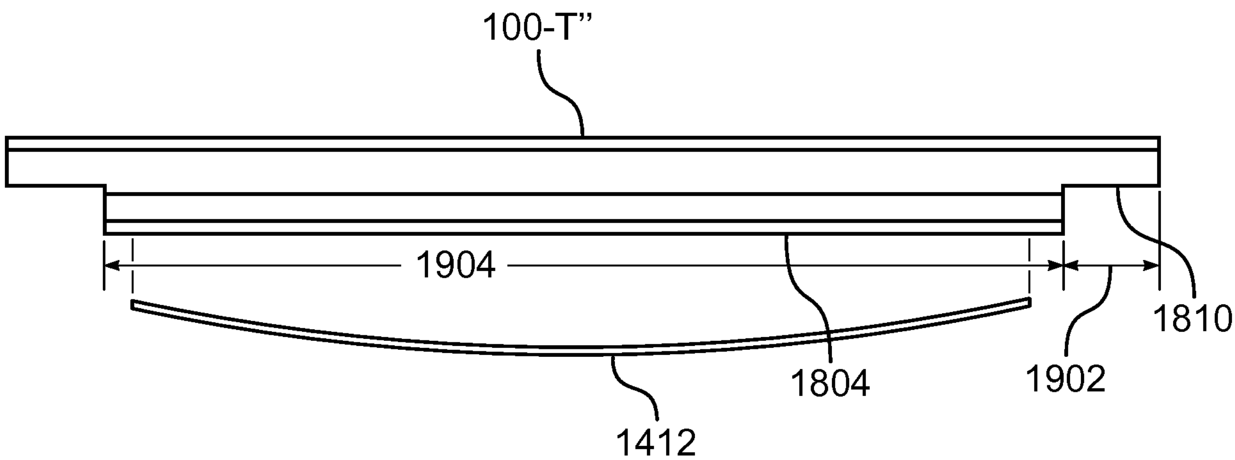


Fig. 19

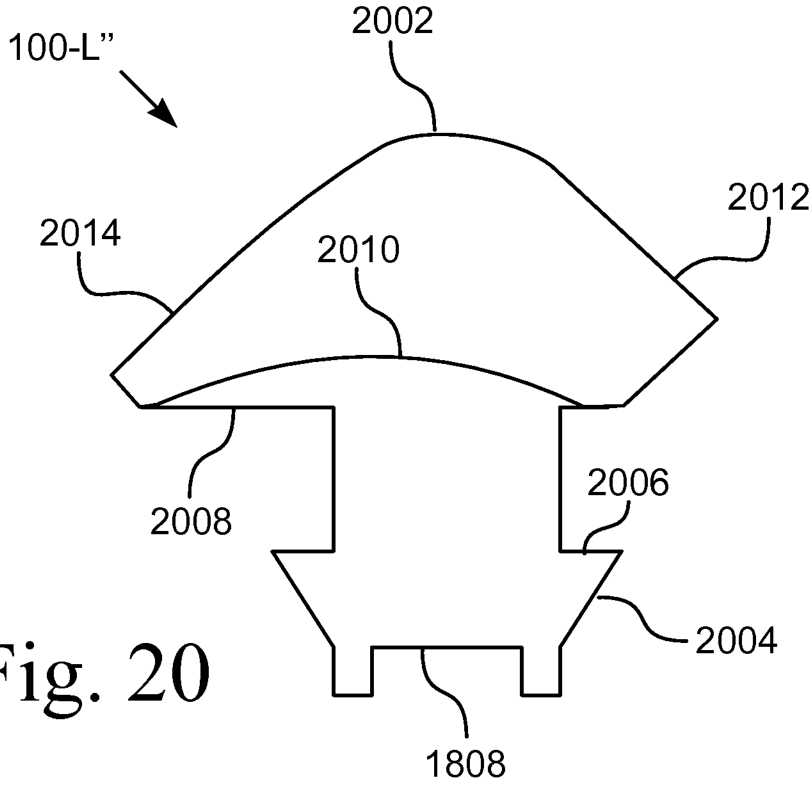

100-L"
2002
2012
2014
2010
2008
2006
2004
1808

Fig. 20

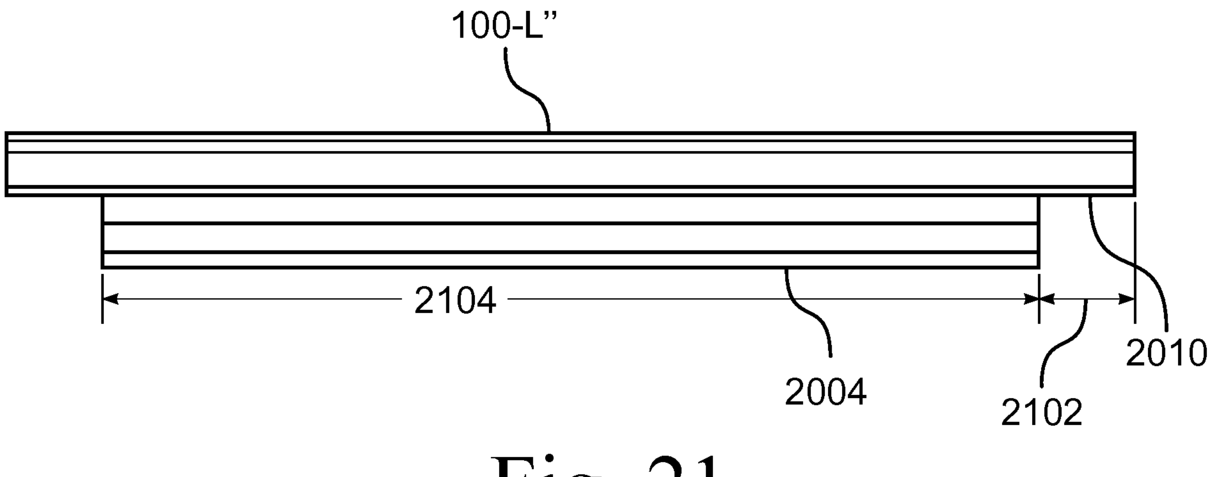

100-L"
2104
2004
2102
2010

Fig. 21

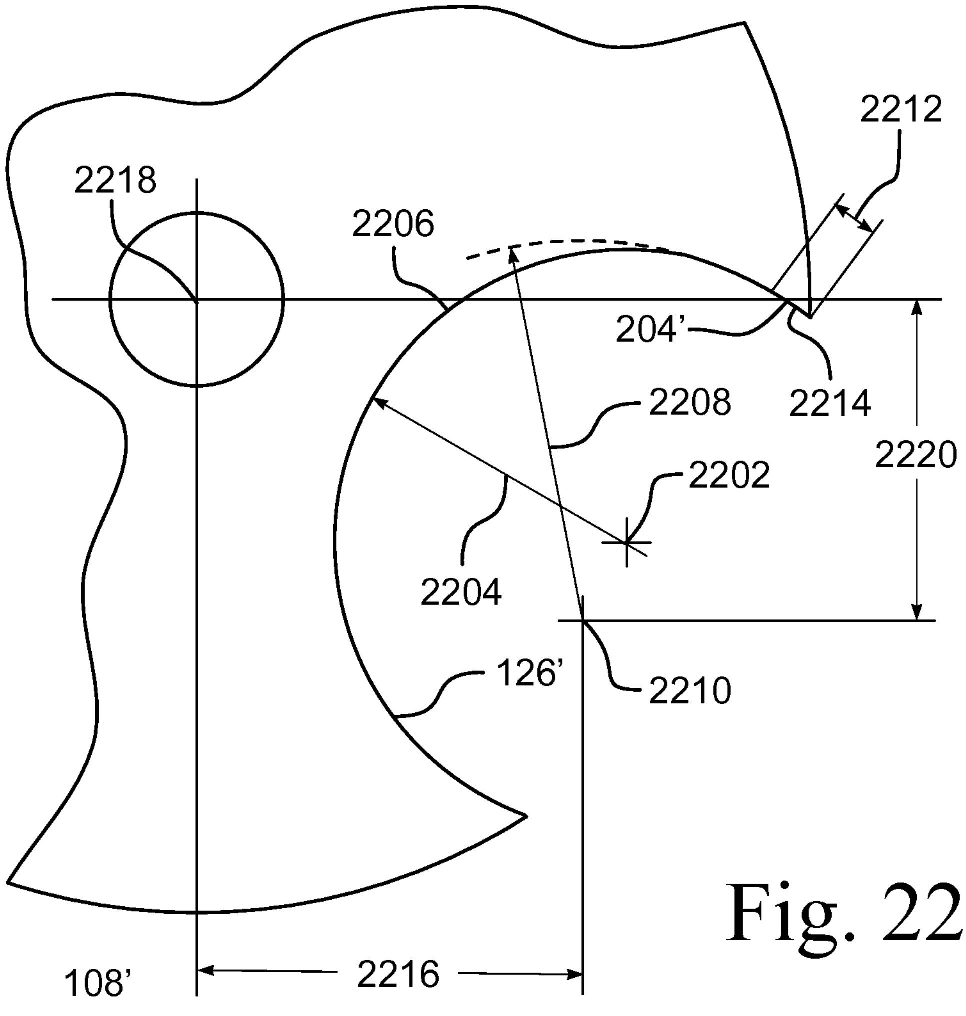


Fig. 22

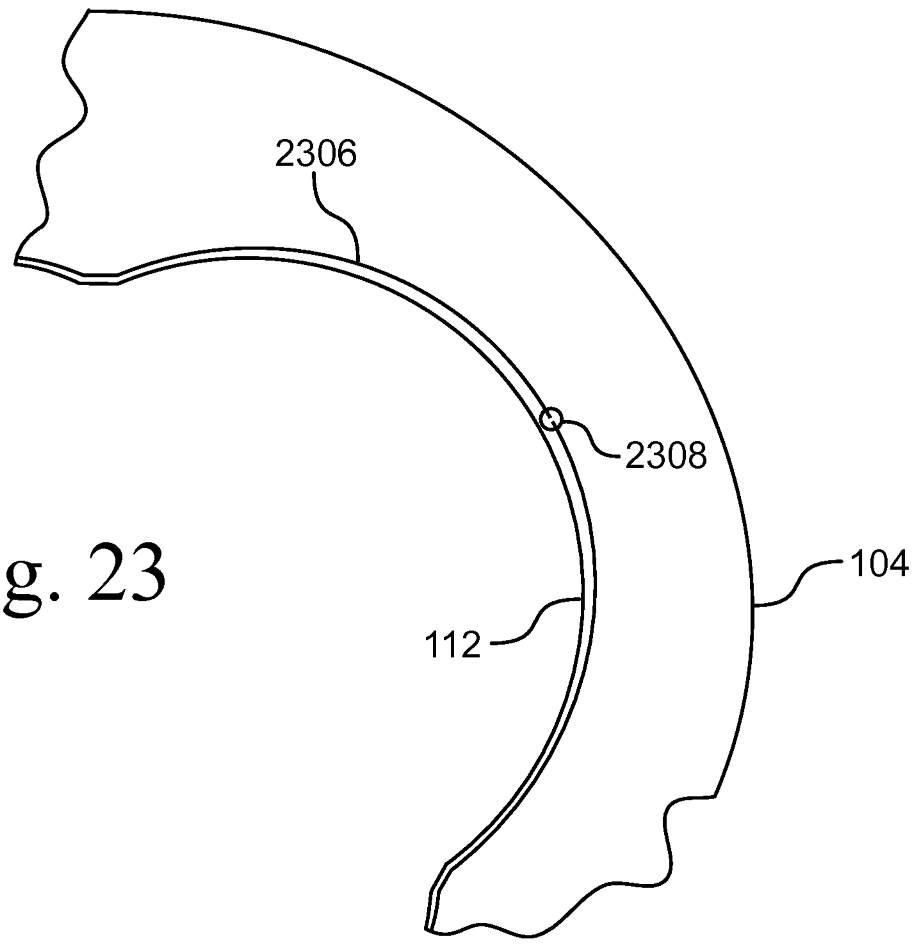


Fig. 23

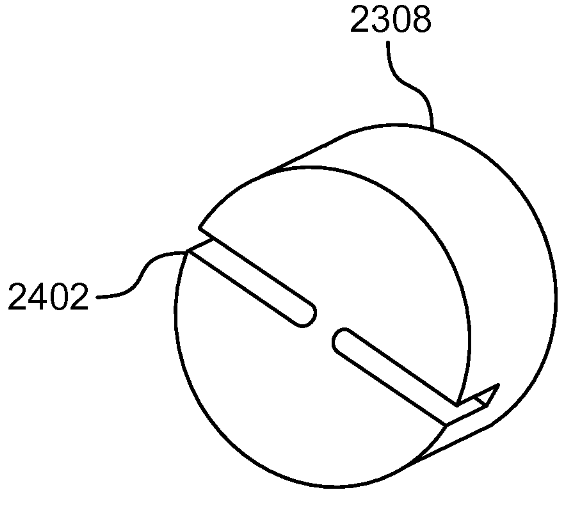


Fig. 24

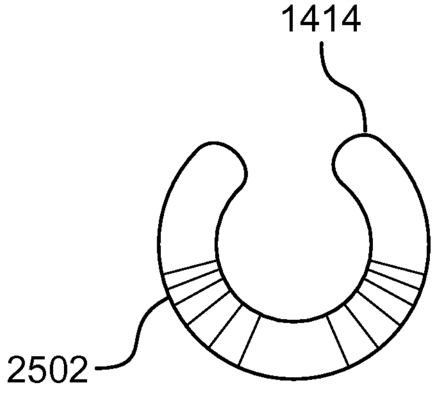


Fig. 25