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**Swartzlander**(10) **Pub. No.: US 2025/0257730 A1**(43) **Pub. Date: Aug. 14, 2025**(54) **OPTIMIZED ENERGY RECOVERY DEVICE**(71) Applicant: **Eaton Intelligent Power Limited,**  
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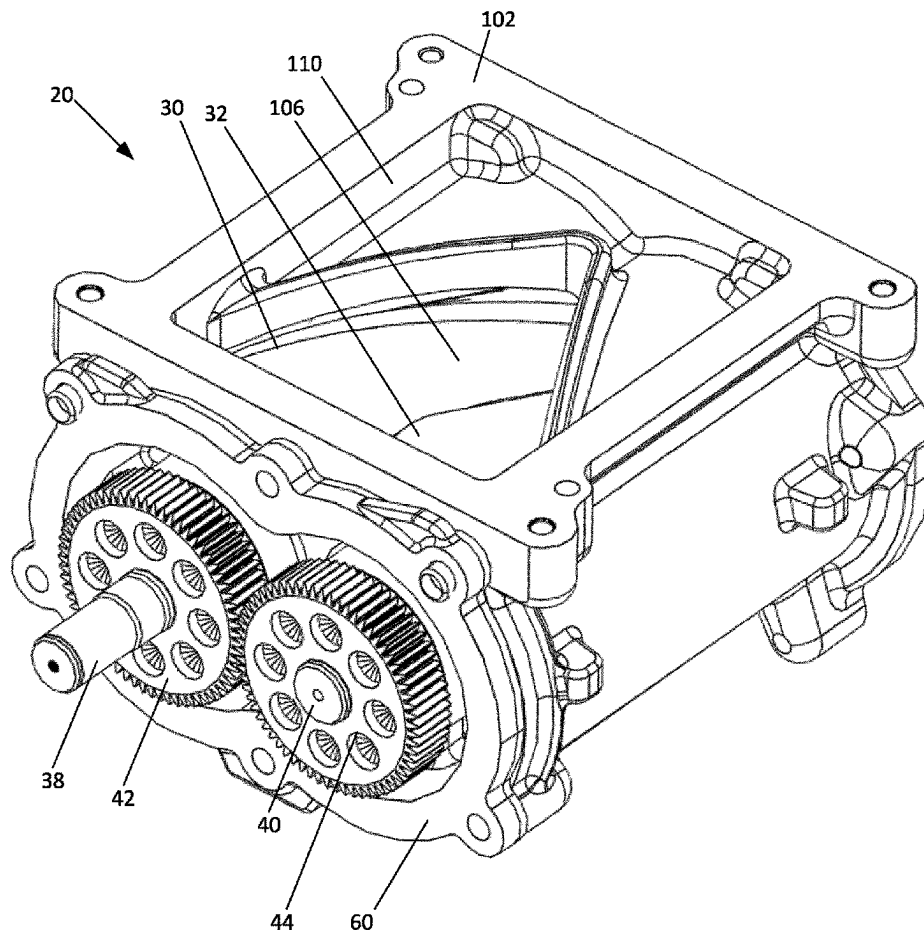
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(2) Date: **Oct. 14, 2024****Related U.S. Application Data**(60) Provisional application No. 63/363,024, filed on Apr.  
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filed on Apr. 29, 2022, provisional application No.  
63/493,606, filed on Mar. 31, 2023.**Publication Classification**(51) **Int. Cl.****F04C 18/12** (2006.01)**F01C 1/12** (2006.01)**F04C 29/12** (2006.01)(52) **U.S. Cl.**CPC ..... **F04C 18/126** (2013.01); **F01C 1/126**(2013.01); **F04C 29/12** (2013.01); **F04C****2240/20** (2013.01); **F04C 2240/30** (2013.01)

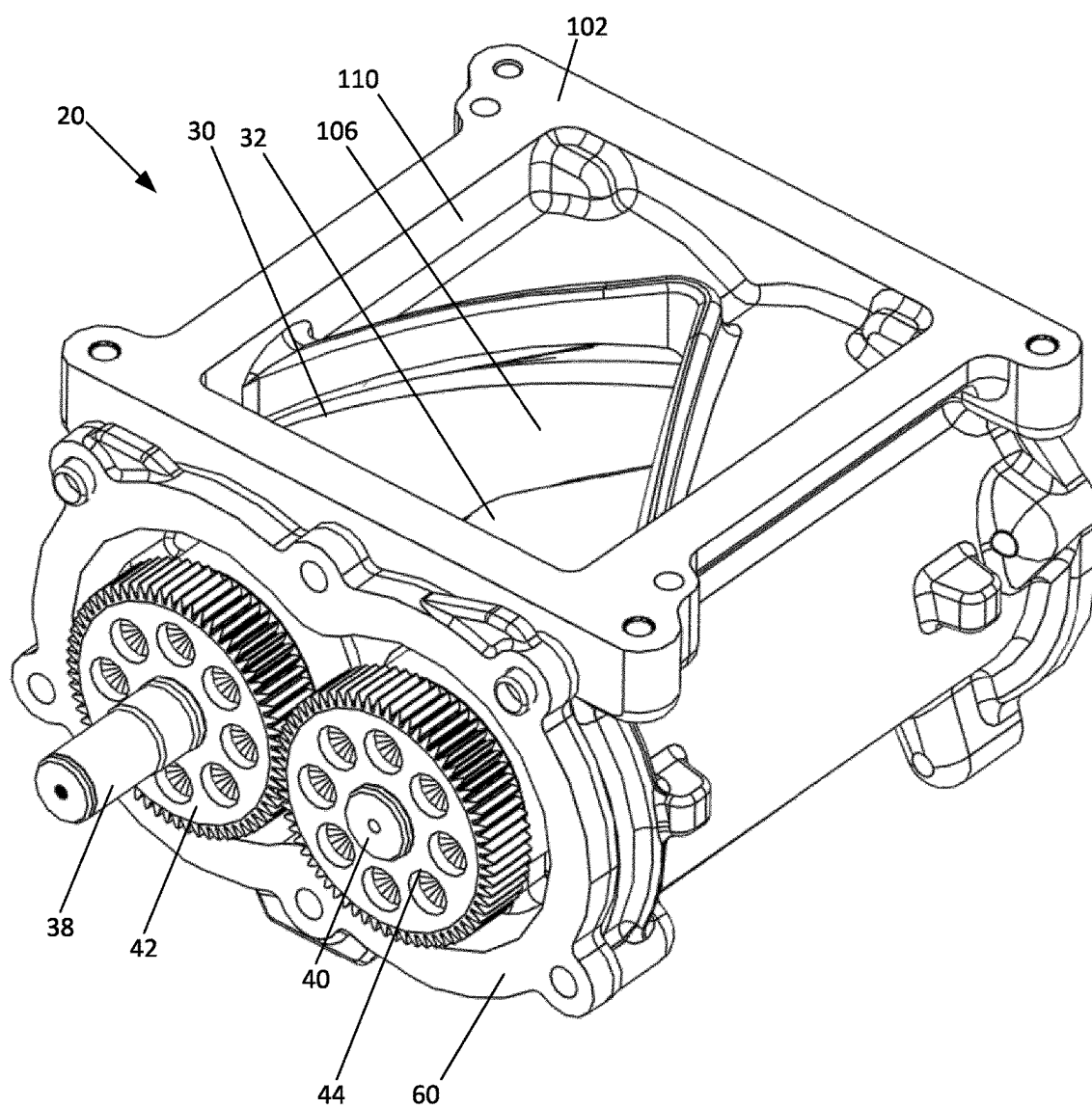
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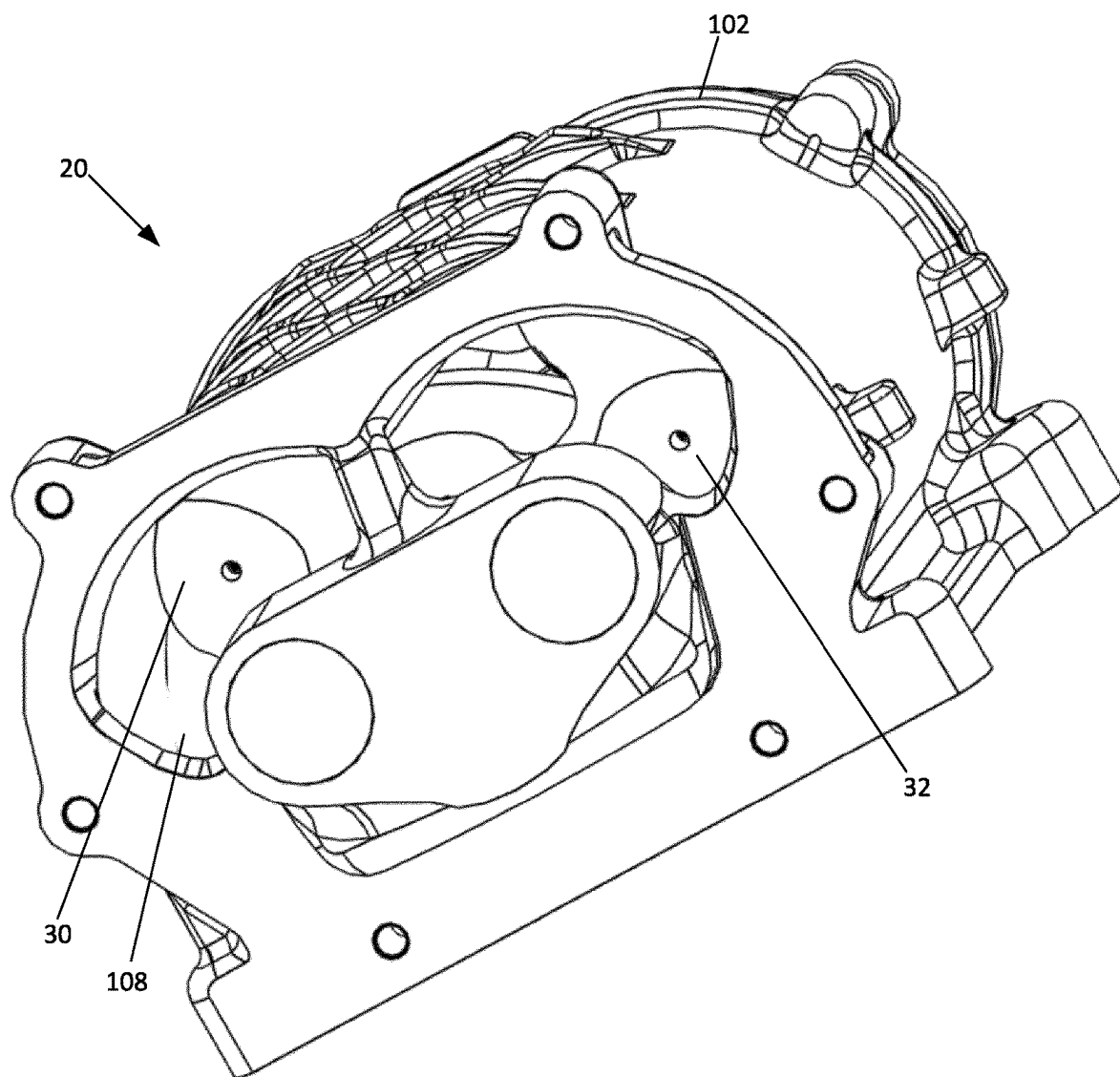
**ABSTRACT**

A Roots-type device can include a housing assembly having a first opening and a second opening in fluid communication with an internal cavity; a pair of identical rotors oppositely arranged within the housing internal cavity, each of the pair of rotors having a longitudinal axis and plurality of lobes, each of the lobes defining an end face extending between a first longitudinal side of the rotor lobe and a second longitudinal side of the rotor lobe; and a recess port defined within the housing assembly and being axially spaced from the end faces of the rotor lobes, the recess port placing the first longitudinal side of one of the rotor lobes in fluid communication with the second longitudinal side of the rotor lobe such that the housing first opening is placed in fluid communication with the housing second opening. The device can also be provided be provided with an inlet nozzle structure in fluid communication with the first opening, the inlet nozzle tapering towards the first opening and being configured such that a nozzle velocity of a working fluid passing through the nozzle is at least equal to the rotor mesh axial lead velocity.

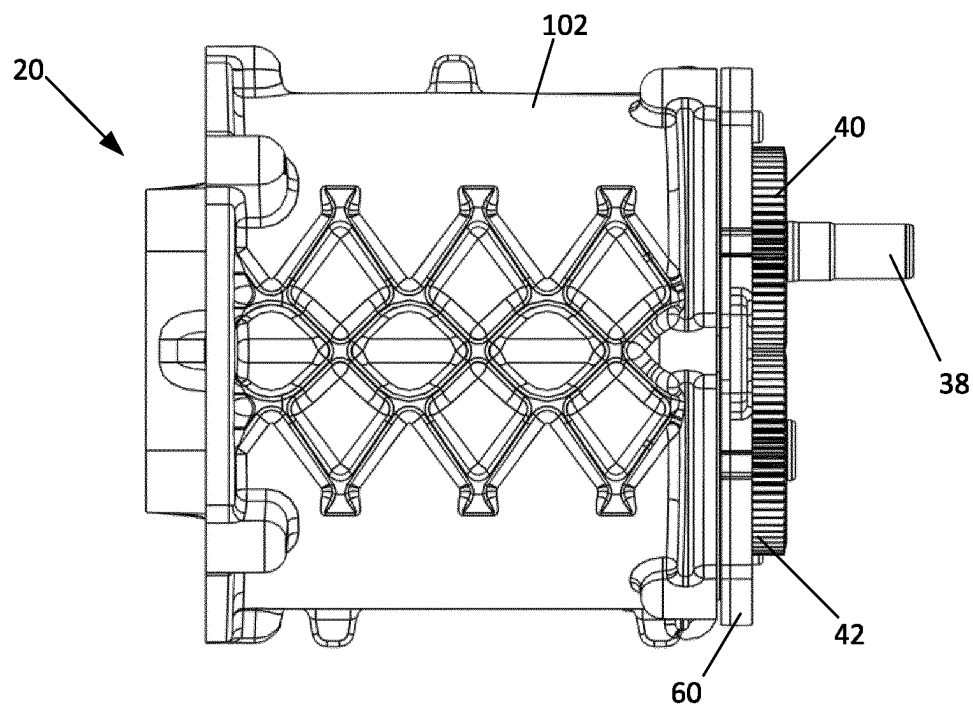


**FIG. 1**

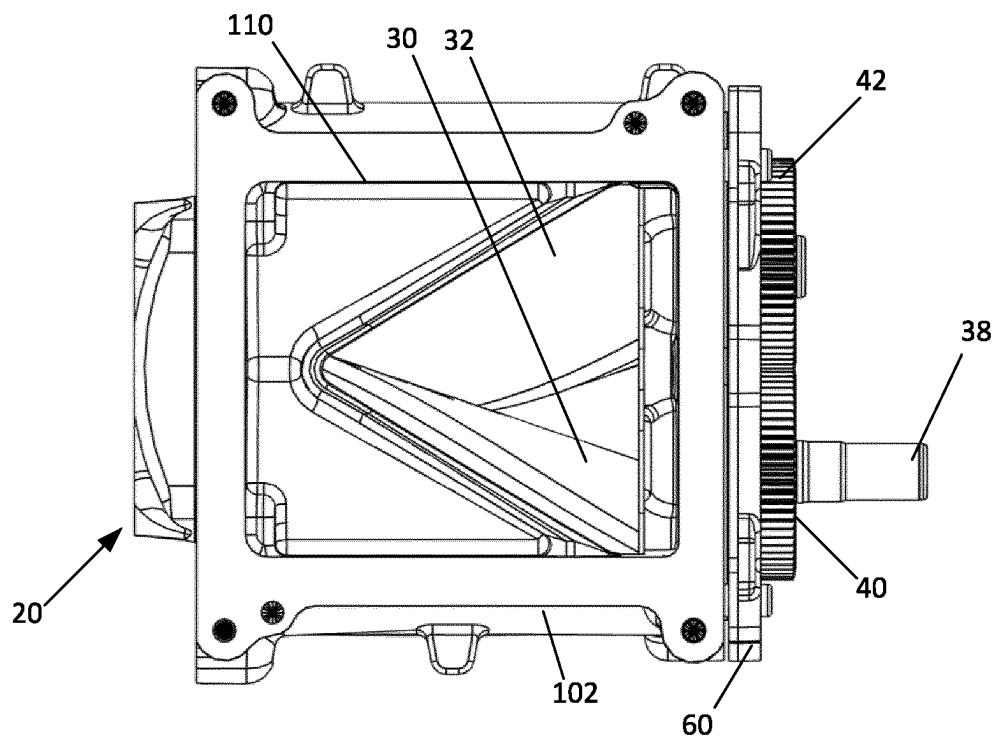


**FIG. 2**

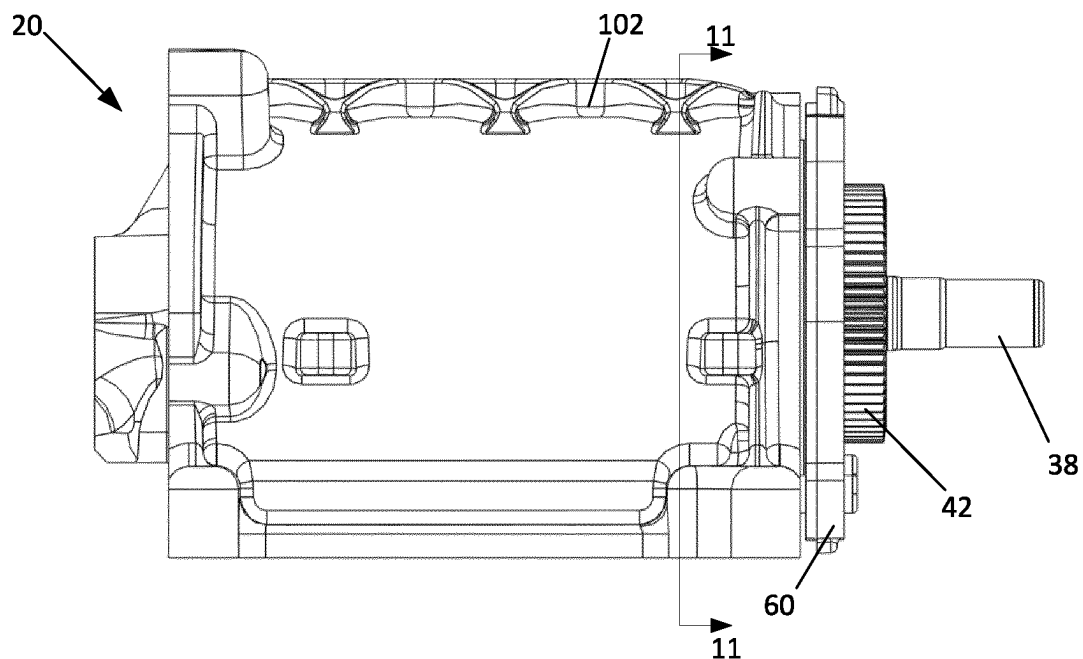
**FIG. 3**



**FIG. 4**



**FIG. 5**



**FIG. 6**

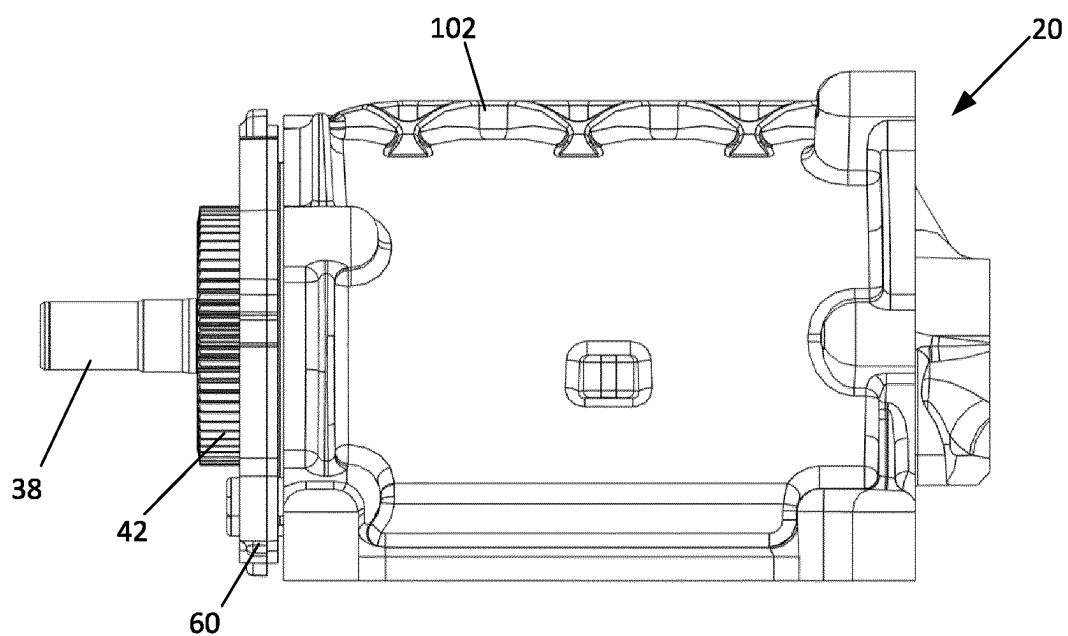


FIG. 7

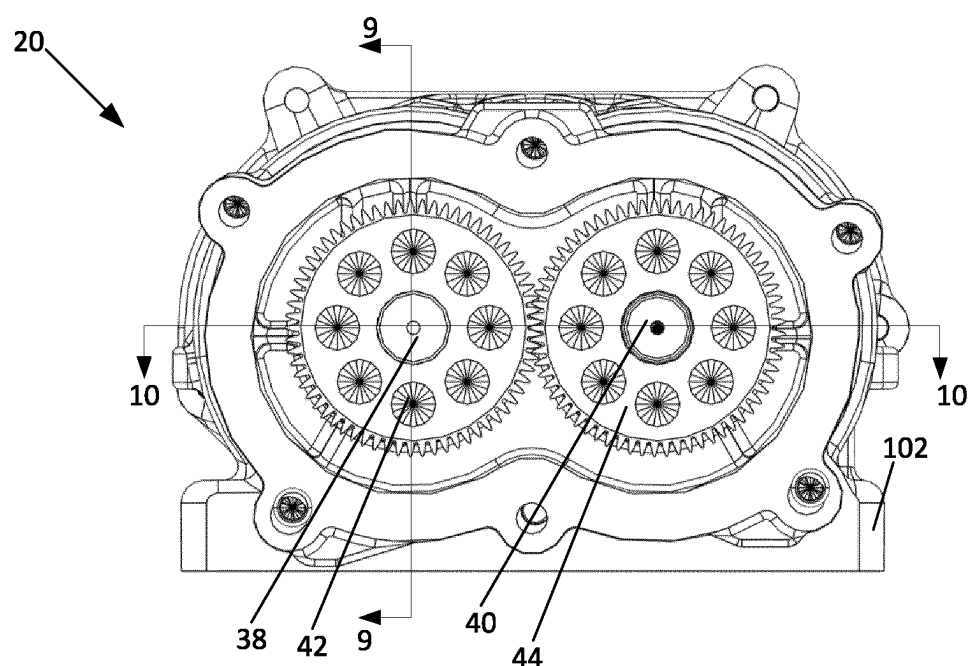
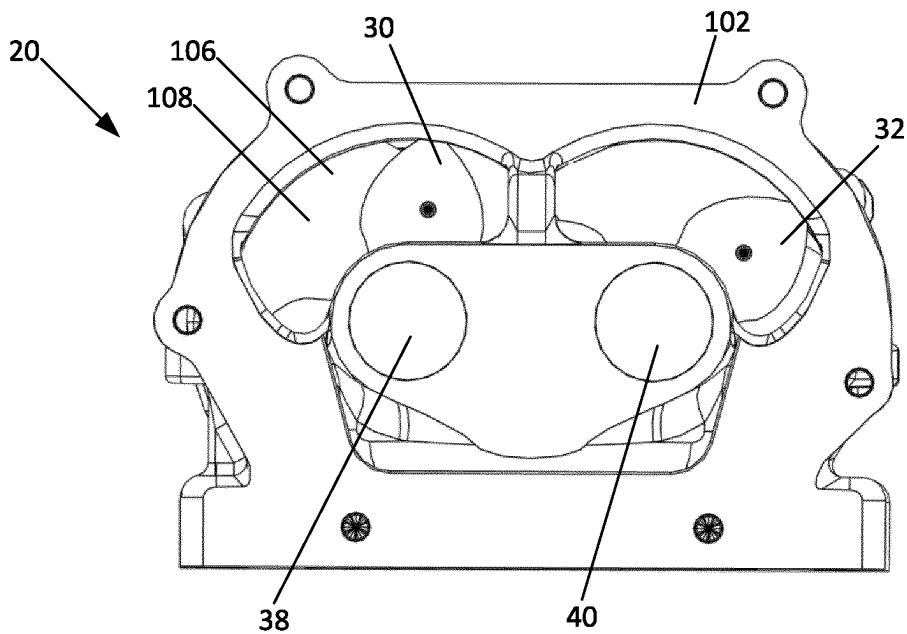
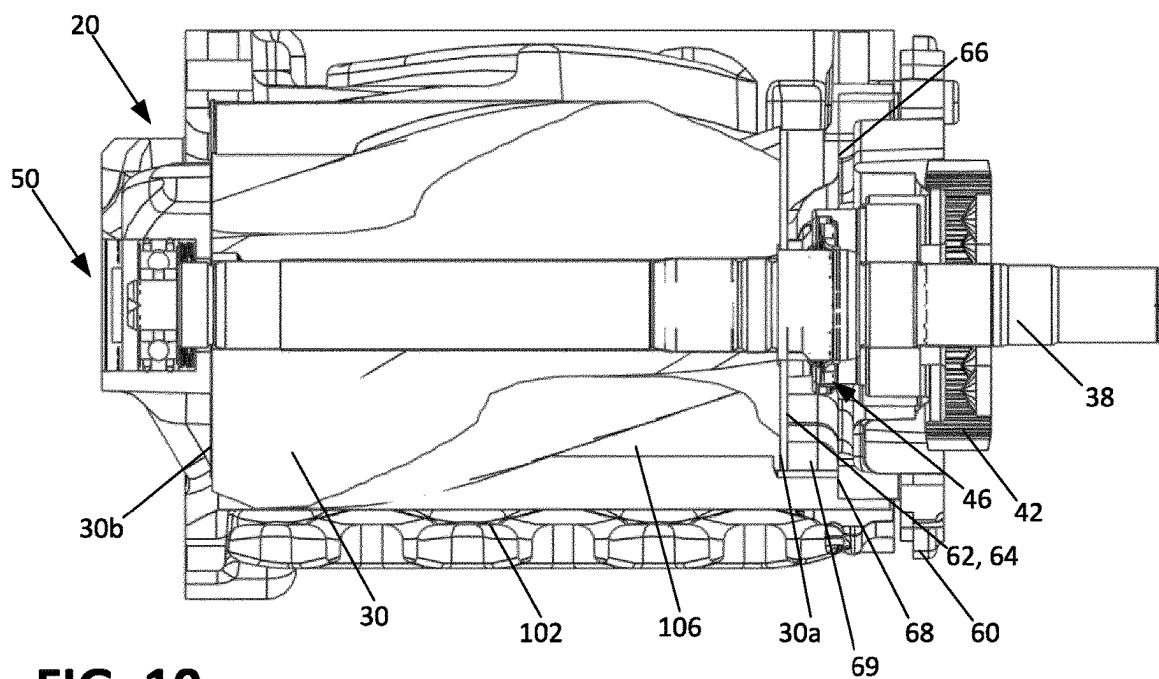


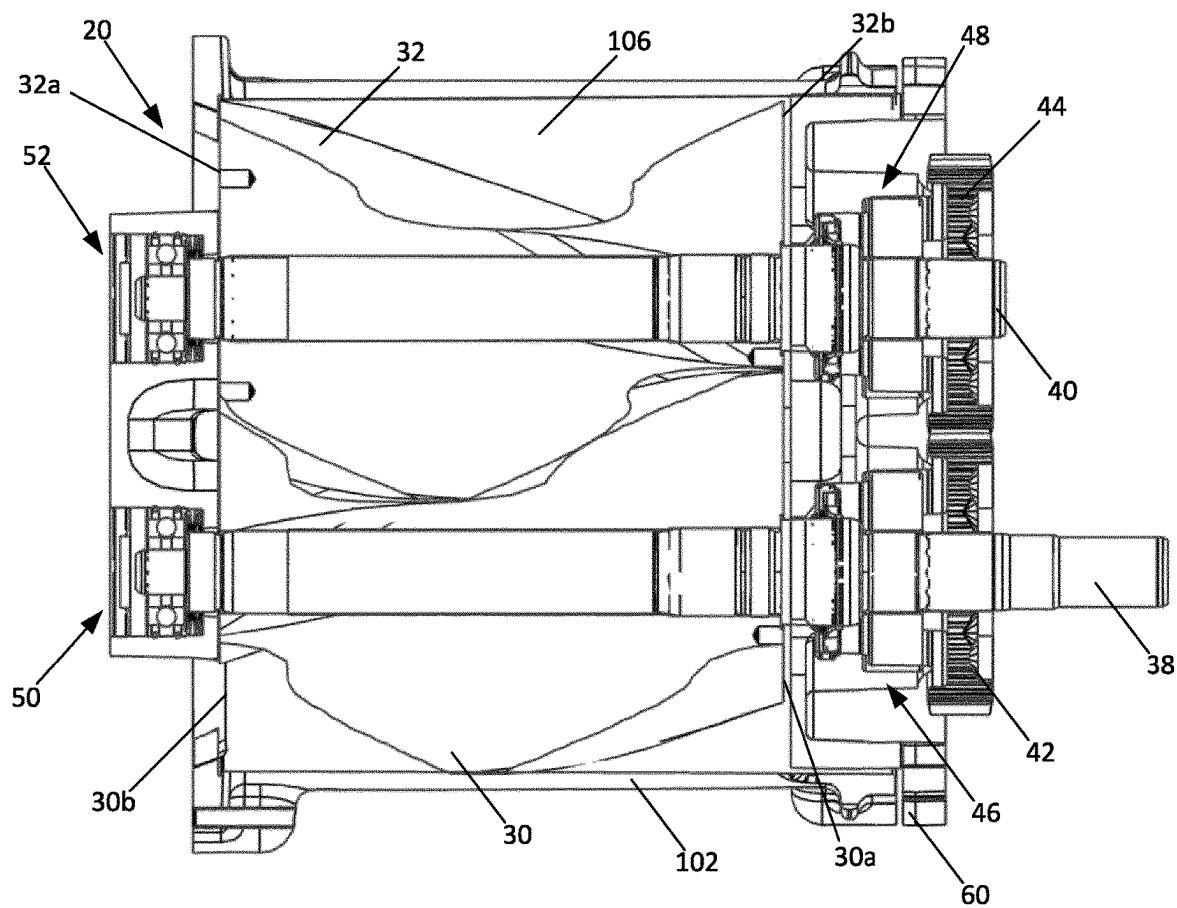
FIG. 8

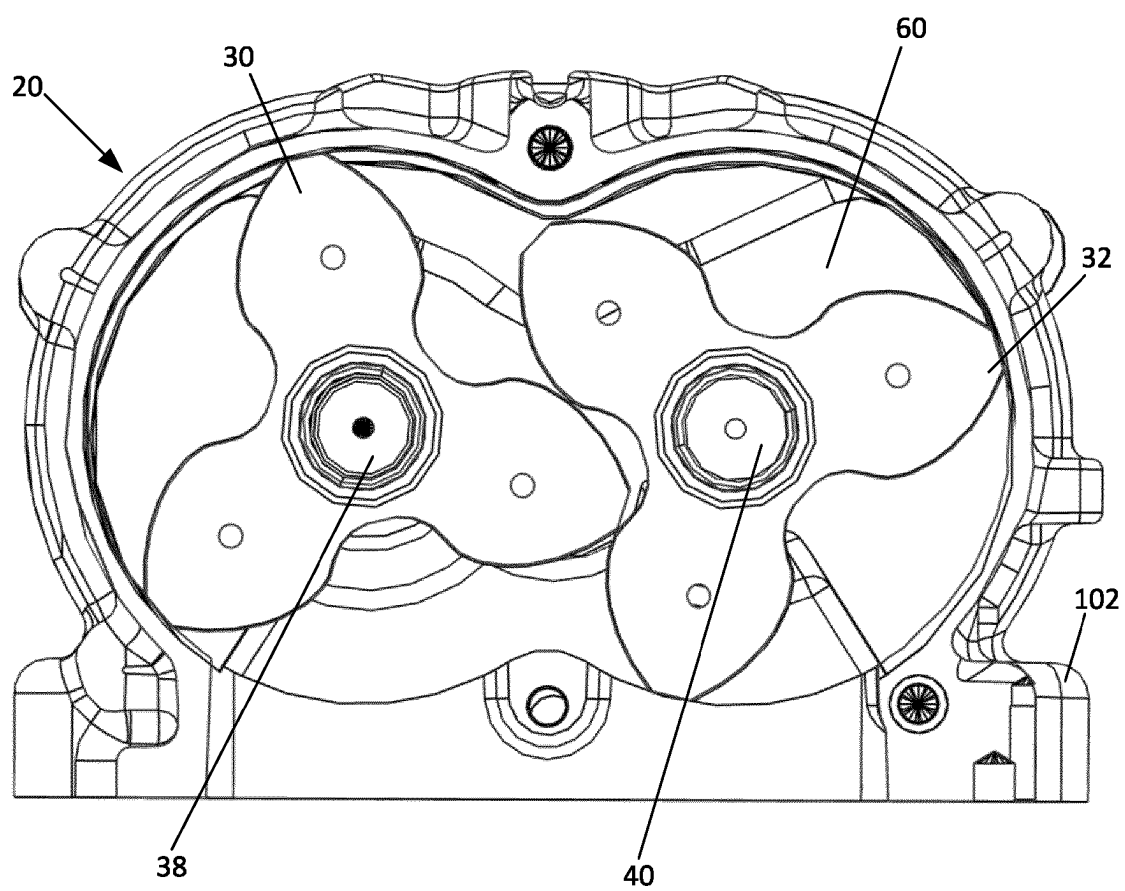


**FIG. 9**



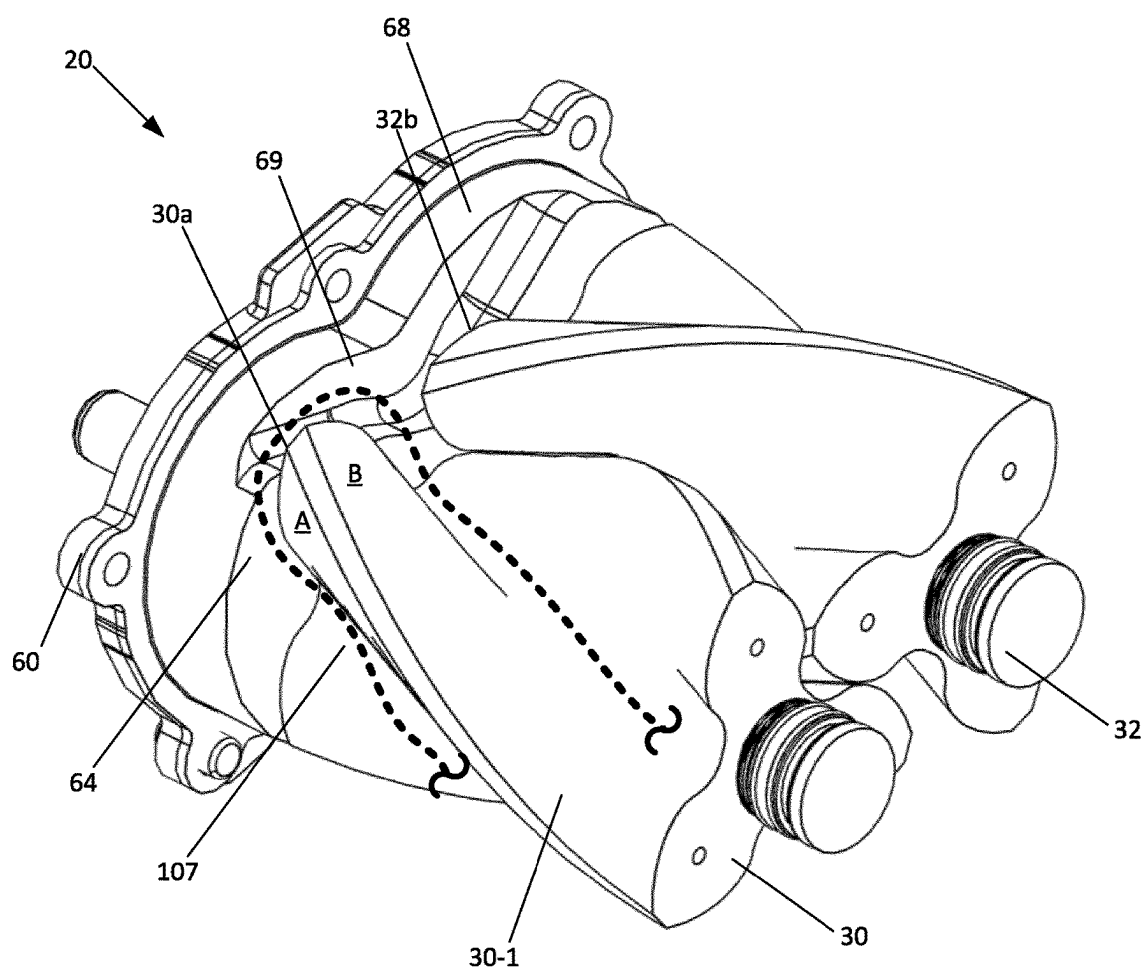
**FIG. 10**



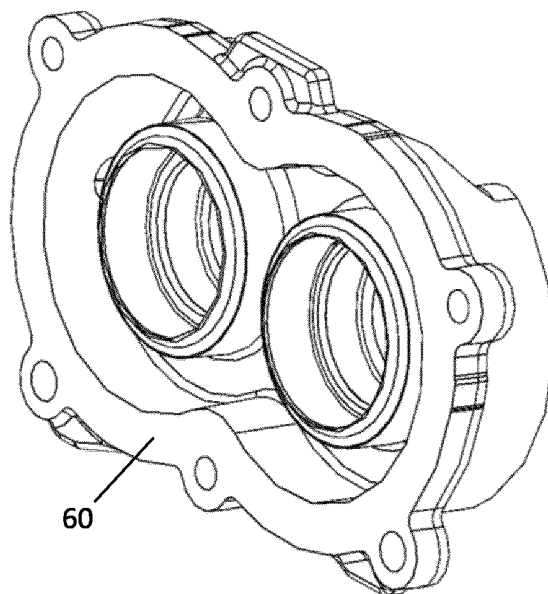
**FIG. 11**



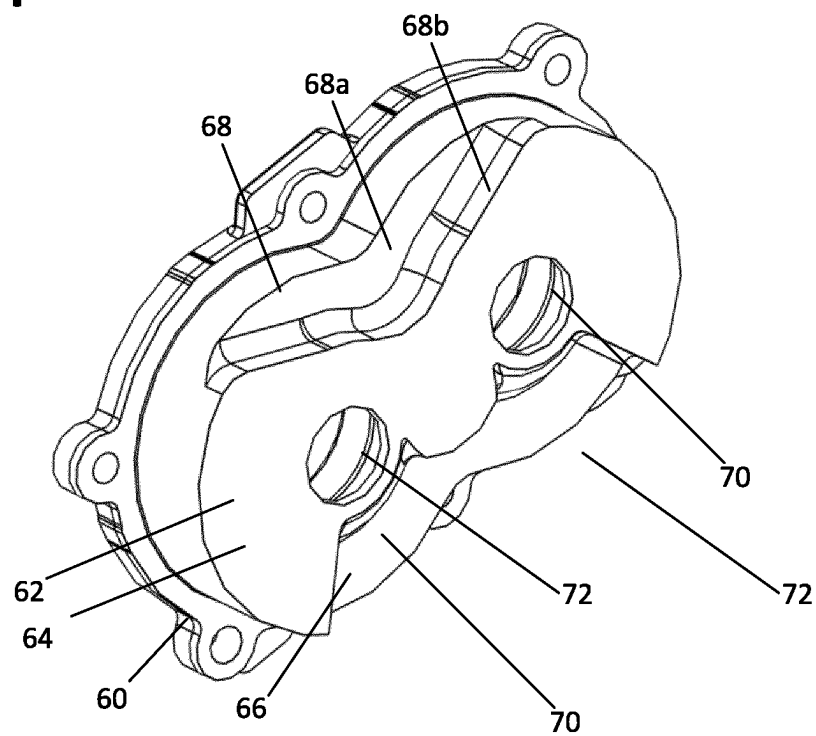
**FIG. 12**



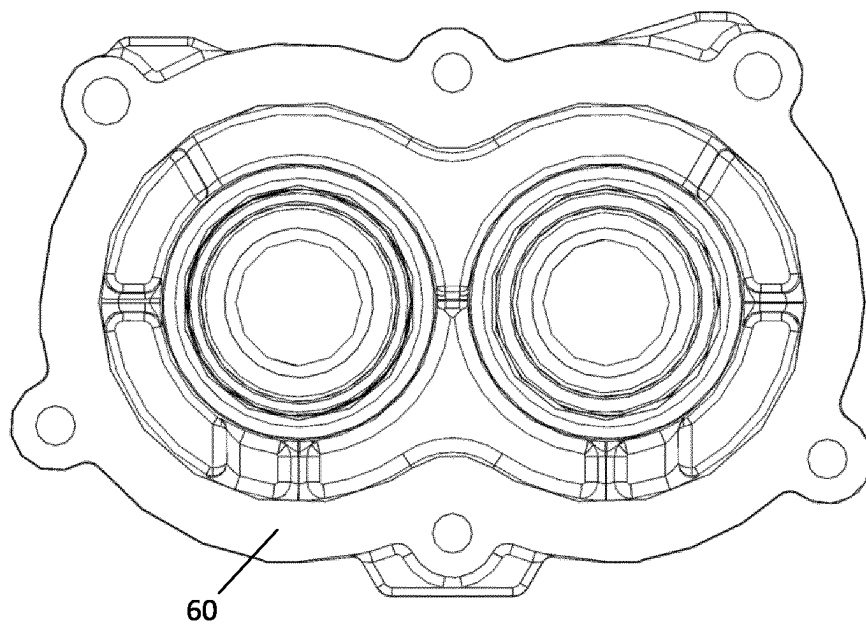
**FIG. 13**



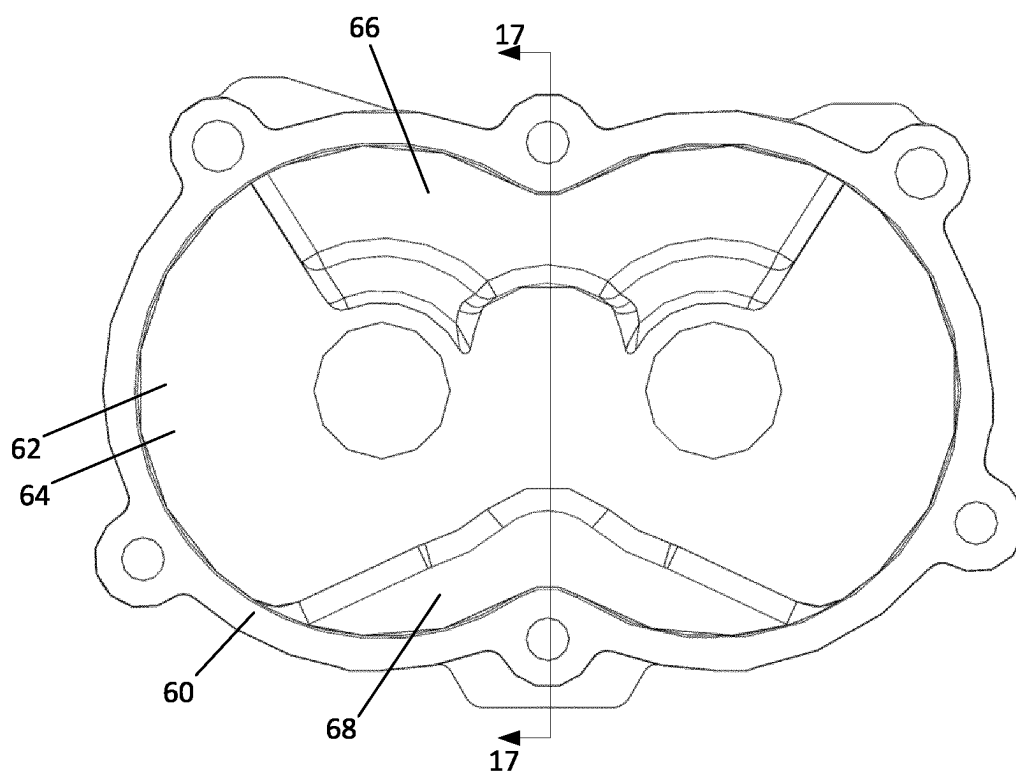
**FIG. 14**



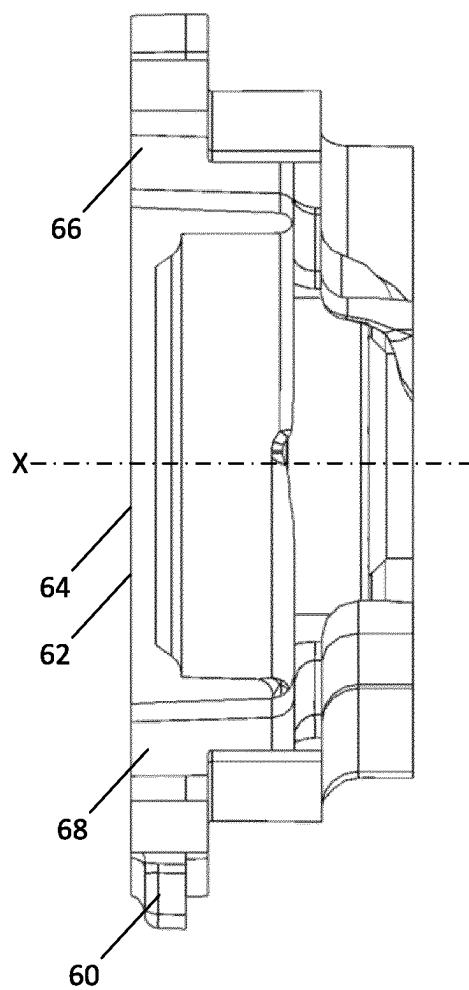
**FIG. 15**



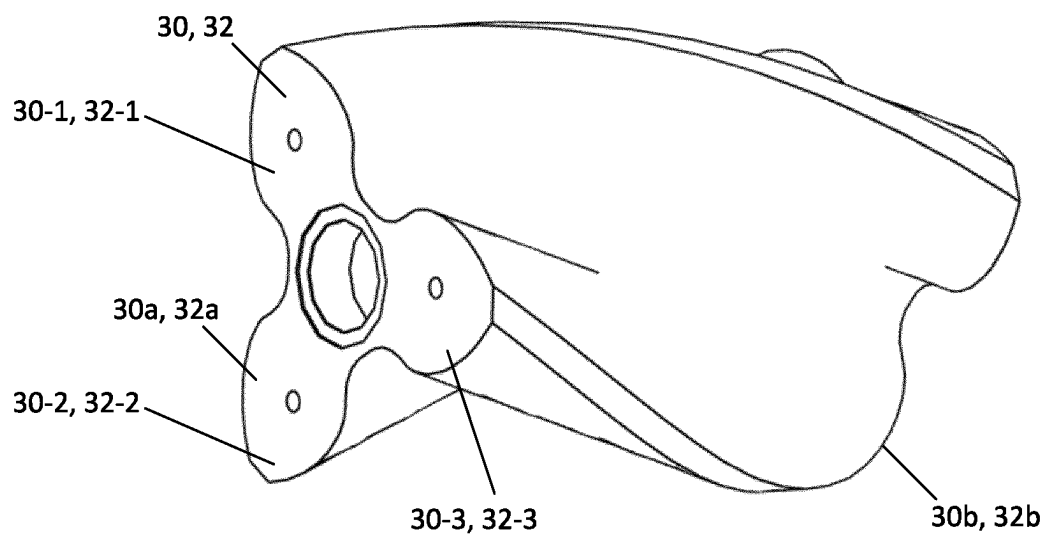
**FIG. 16**



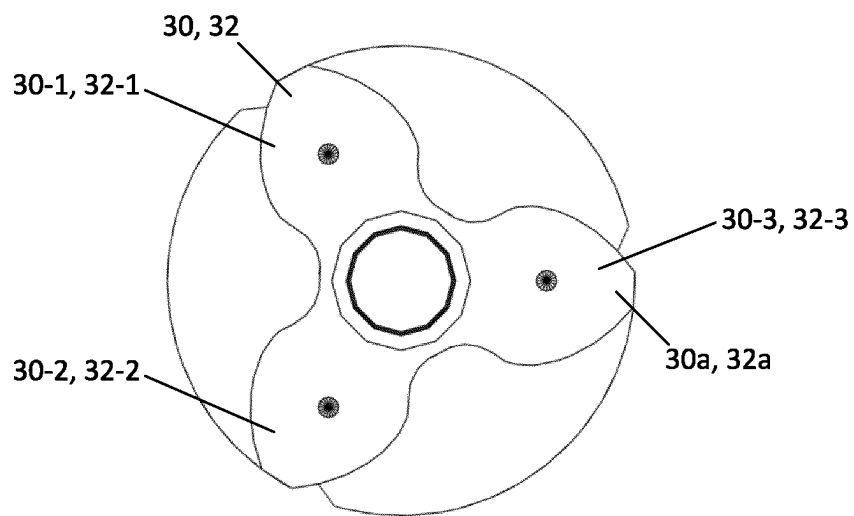
**FIG. 17**



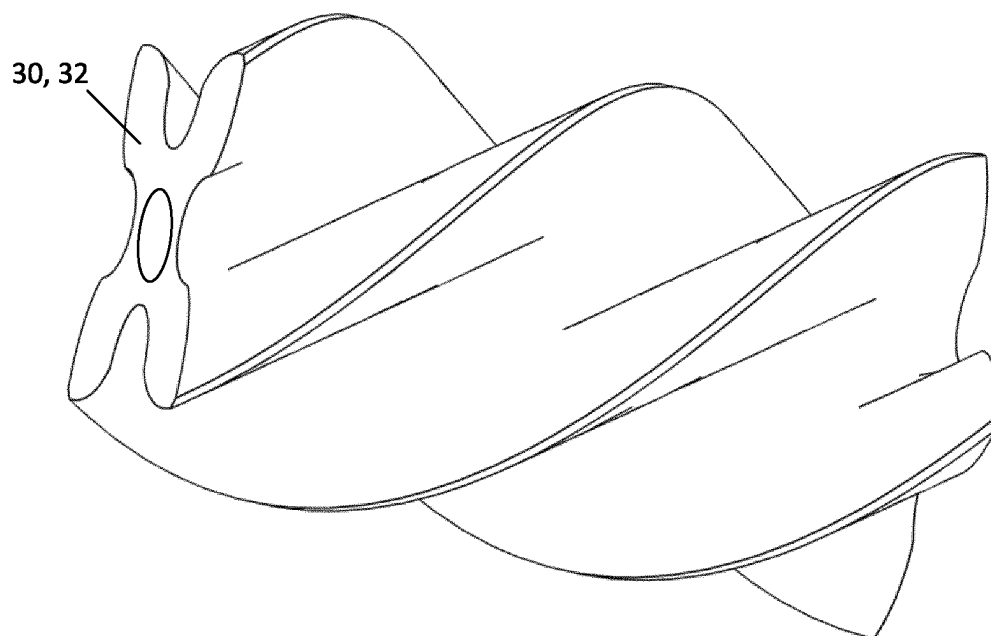
**FIG. 18**



**FIG. 19**



**FIG. 20**



**FIG. 21**

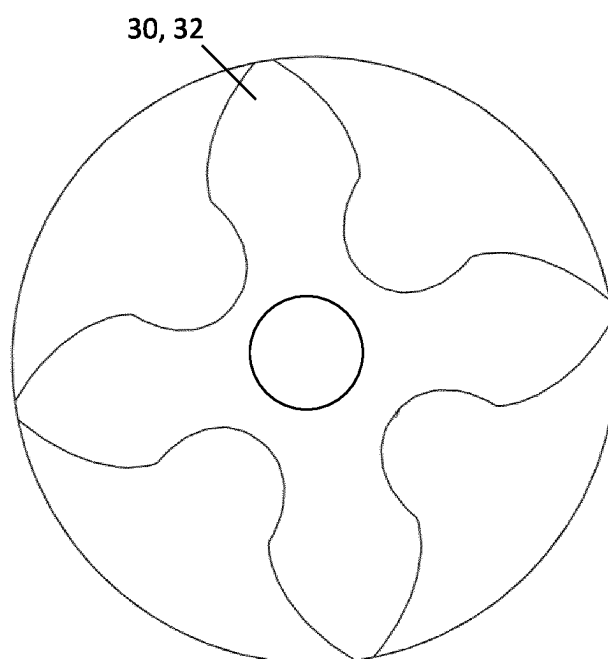
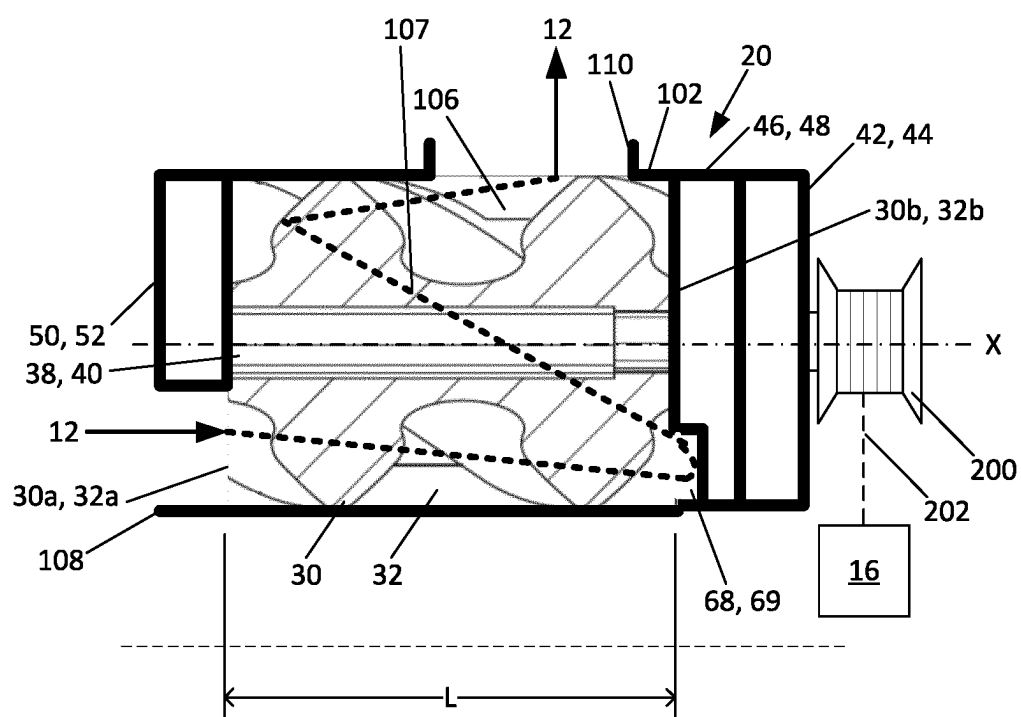
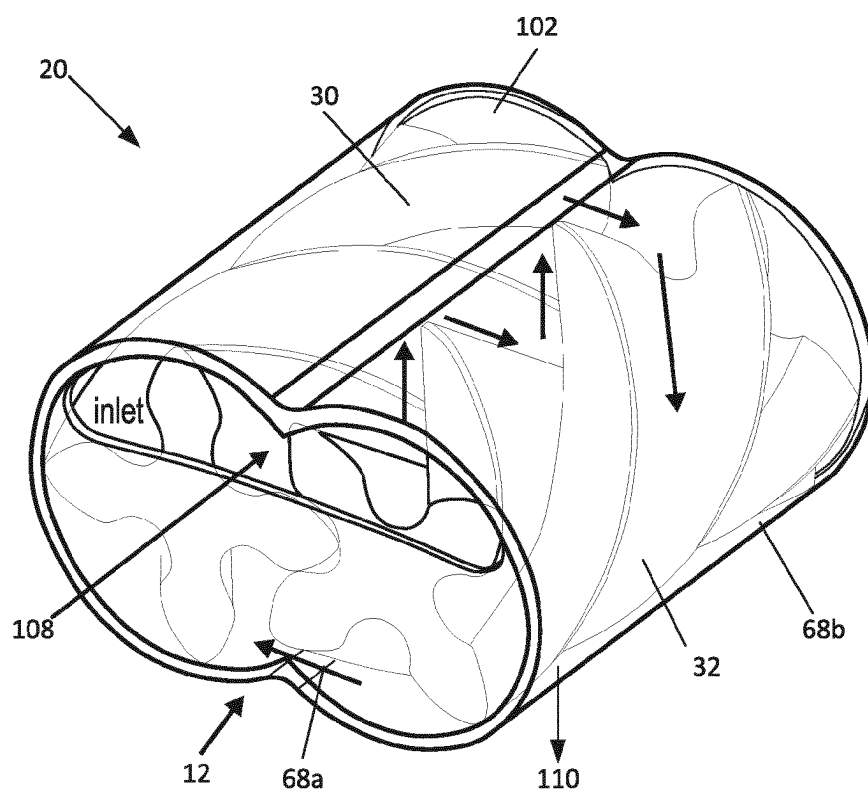


FIG. 22



**FIG. 23**







**FIG. 25**

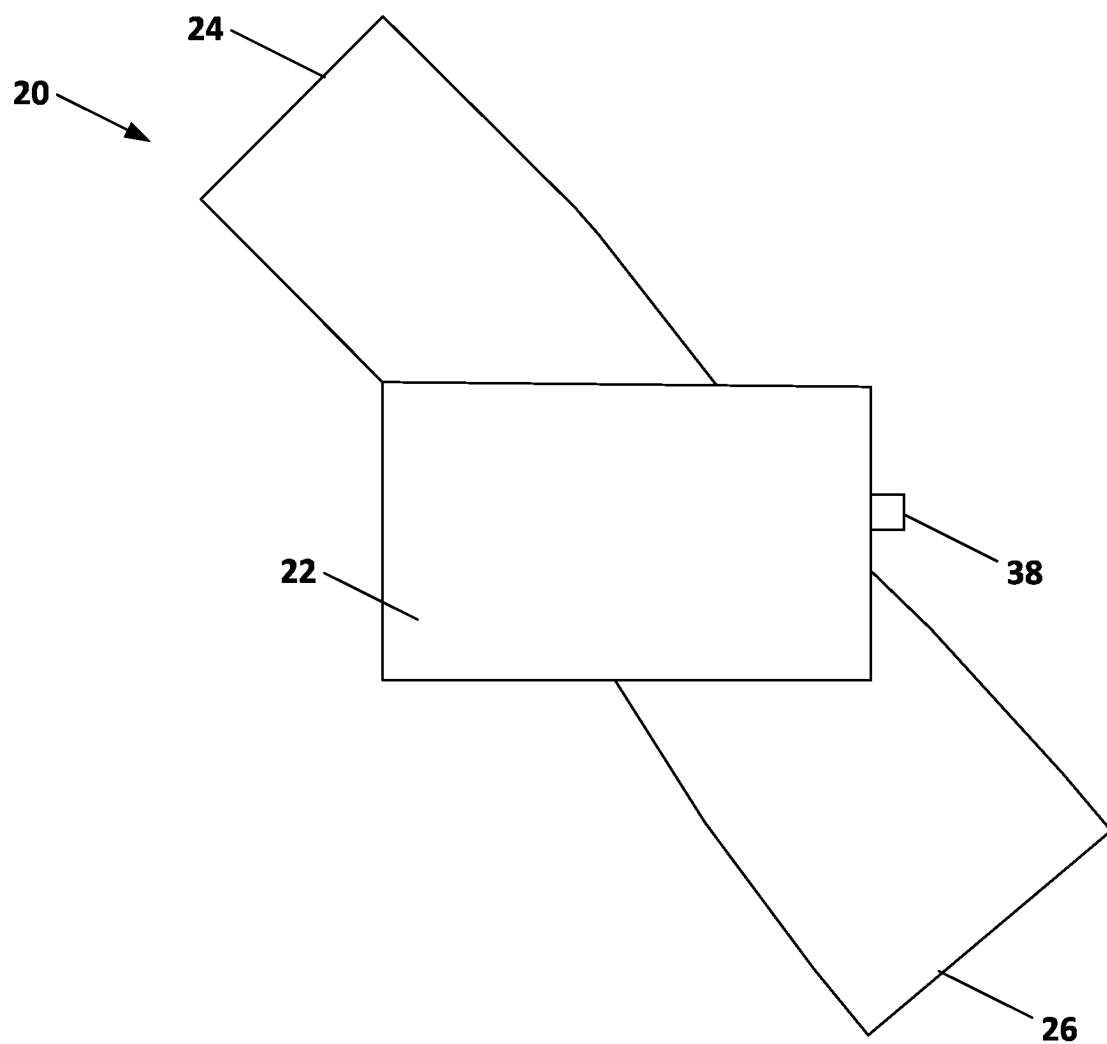


FIG. 26

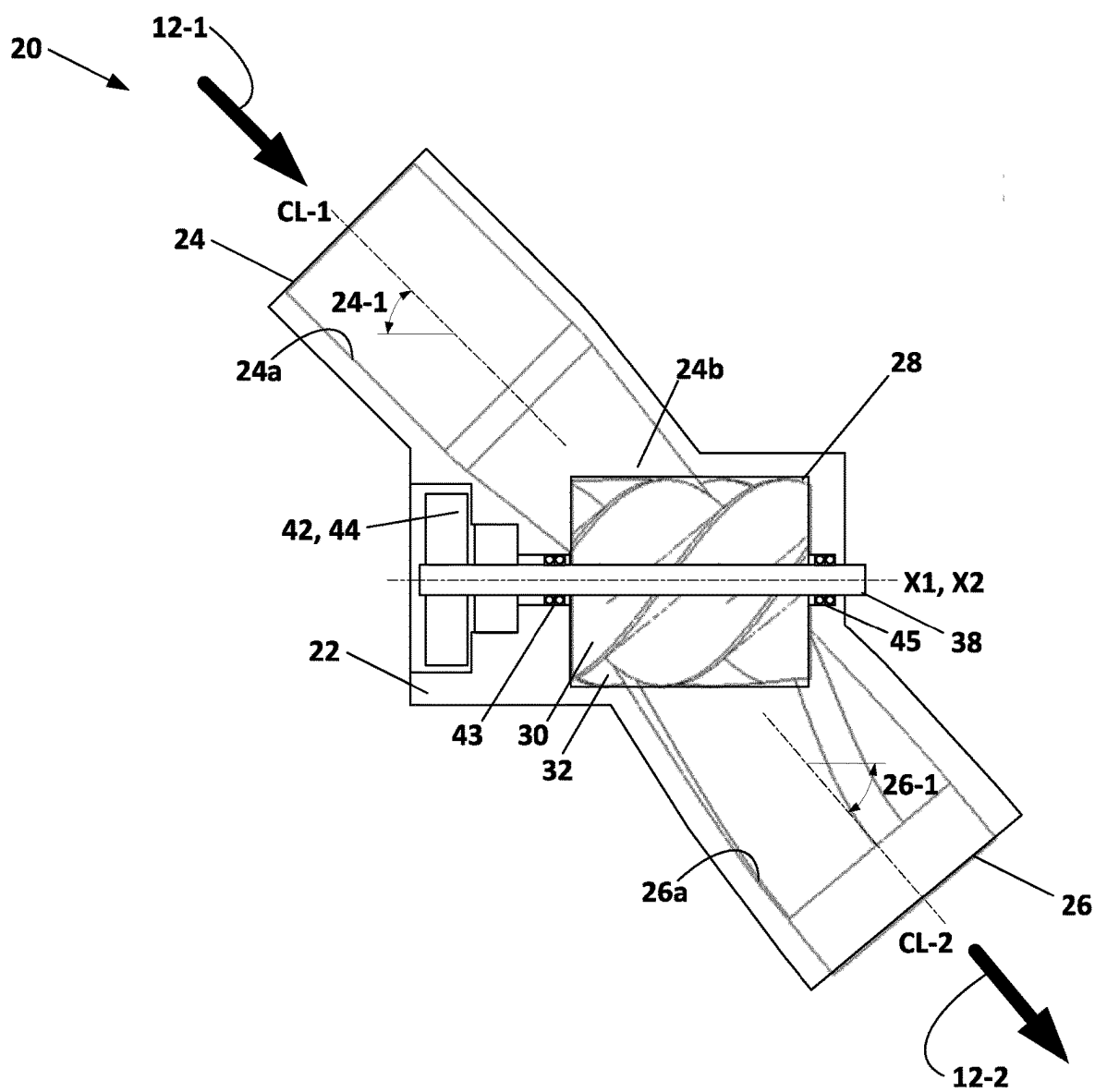


FIG. 27

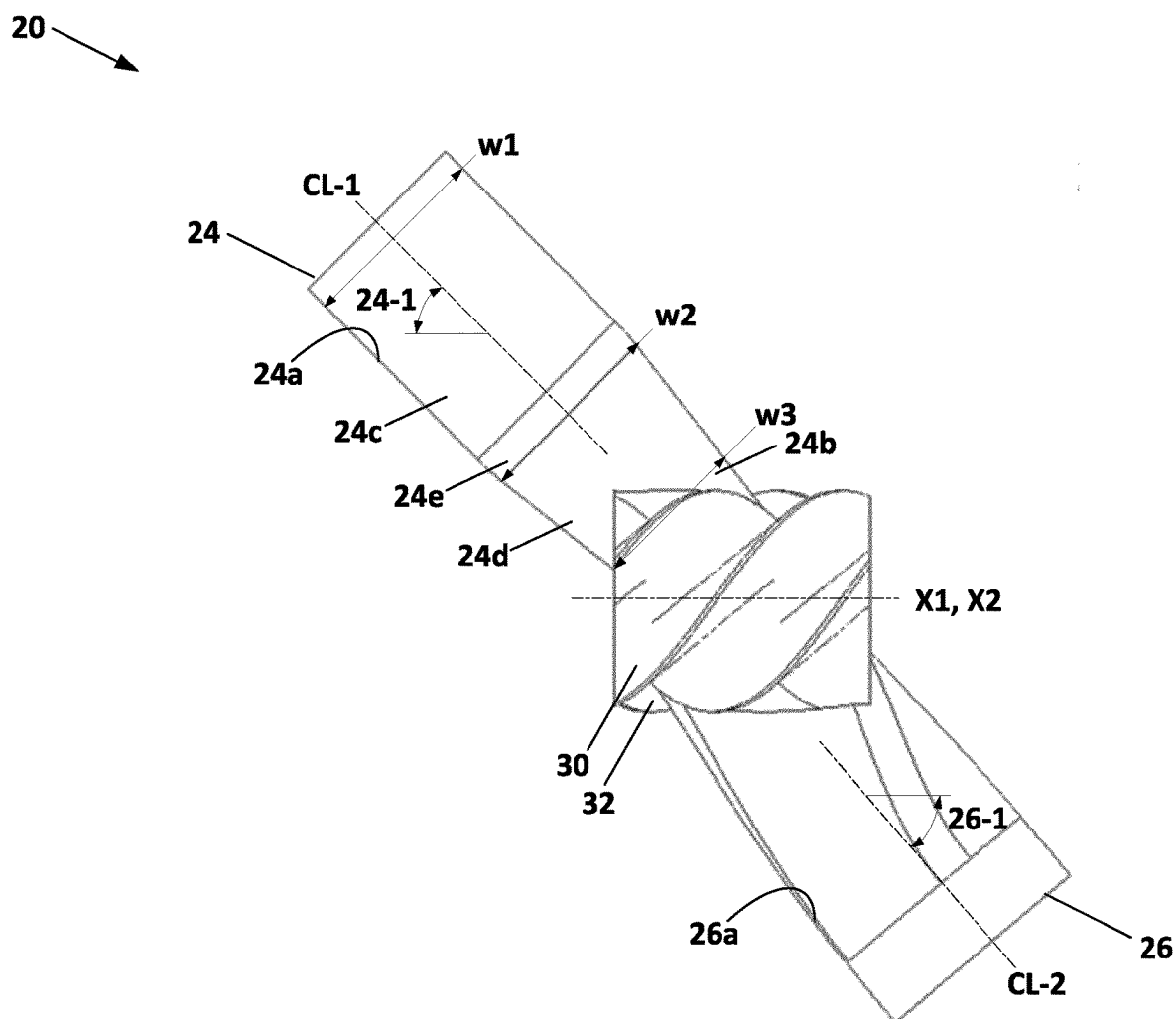
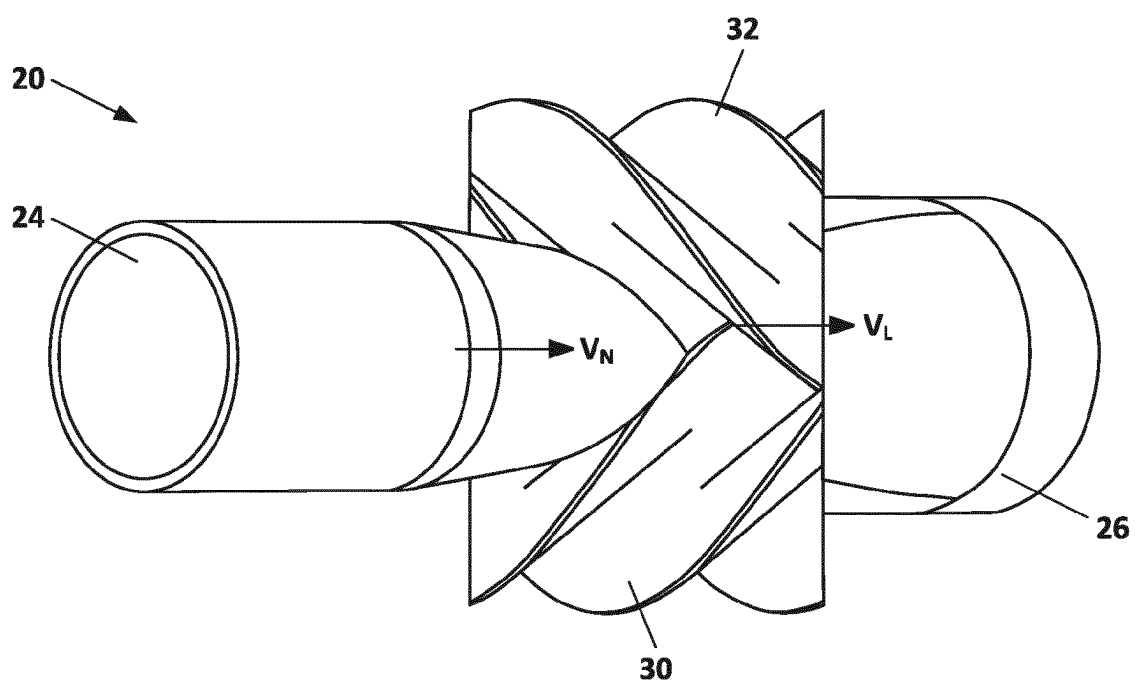
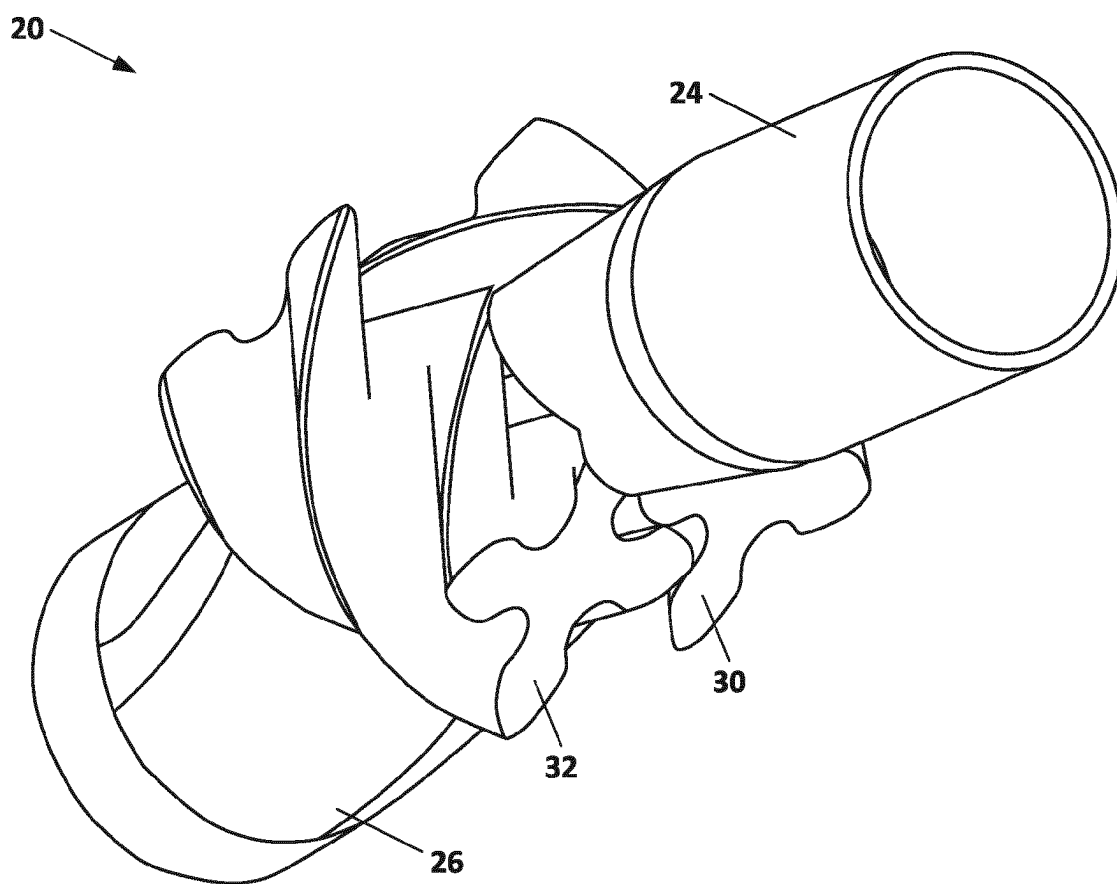


FIG. 28



**FIG. 29**



**FIG. 30**

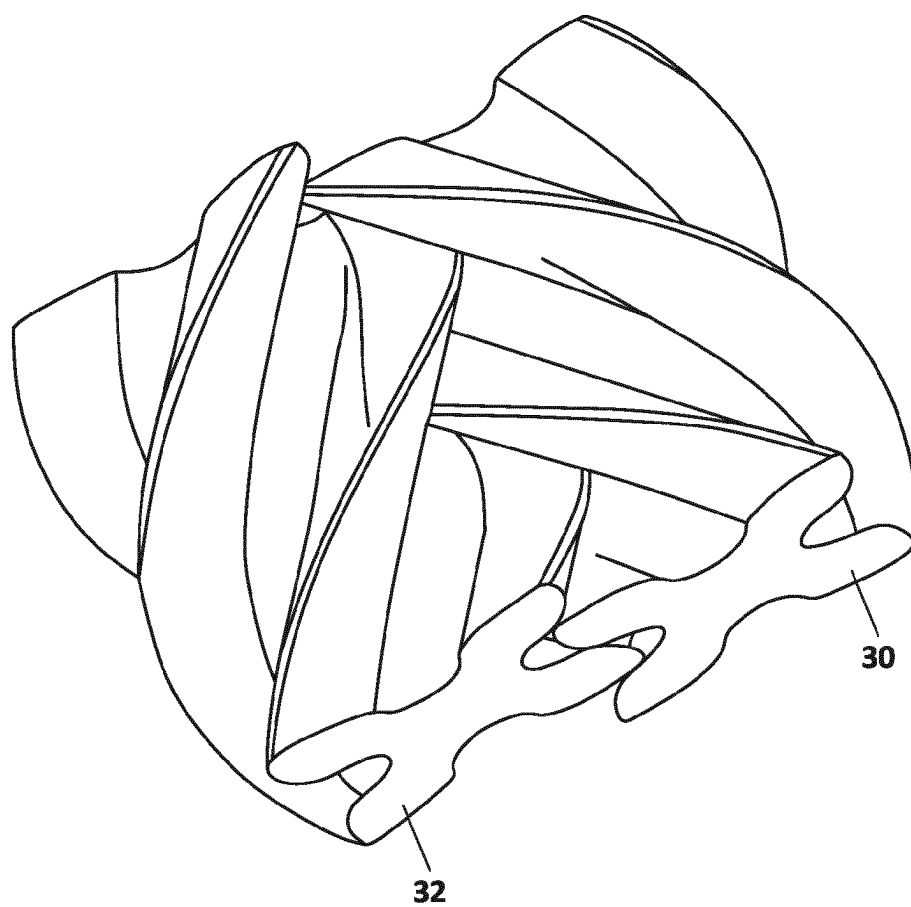
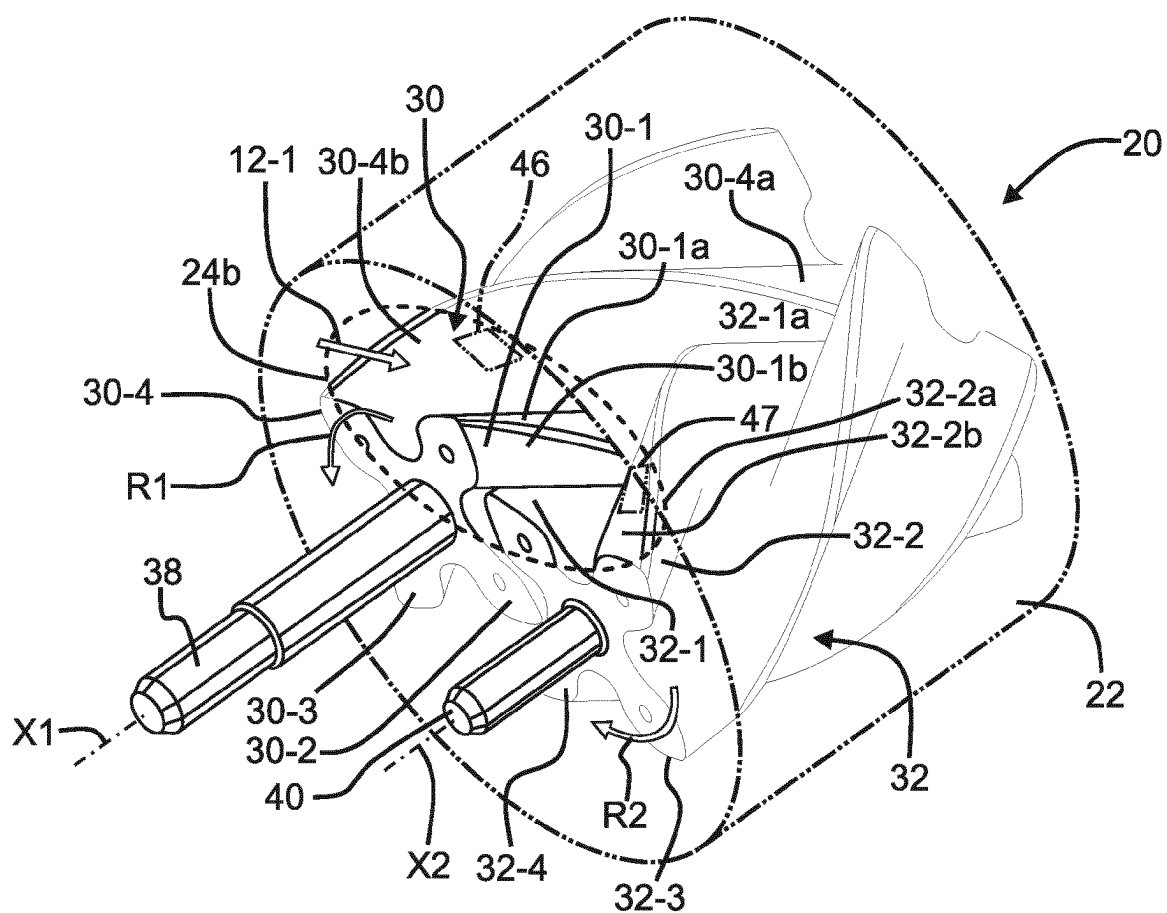
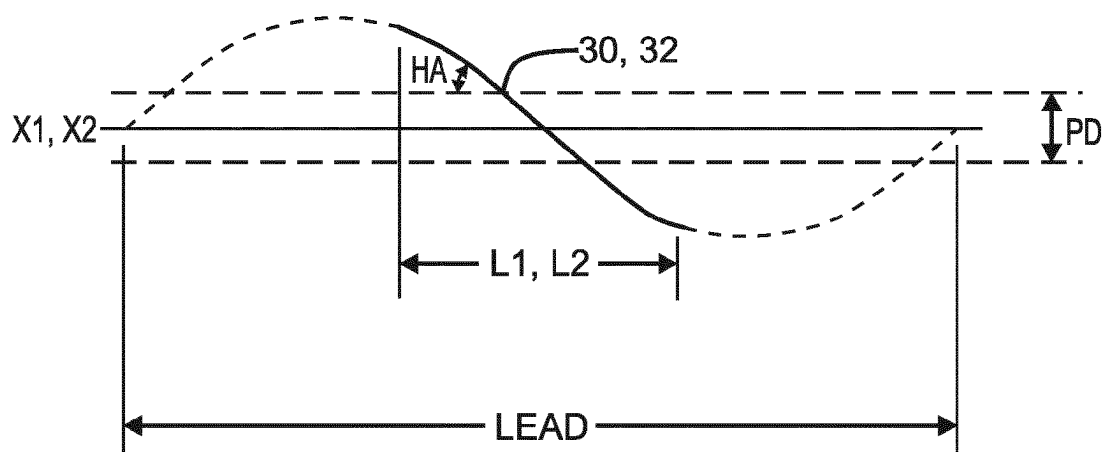


FIG. 31





**FIG. 32**



**OPTIMIZED ENERGY RECOVERY DEVICE****RELATED APPLICATIONS**

**[0001]** This application is being filed on Apr. 14, 2023, as a PCT International Patent application and claims the benefit of and priority to U.S. Provisional application Nos. 63/363,024, filed Apr. 14, 2022; 63/336,483, filed Apr. 29, 2022; and 63/493,606, filed on Mar. 31, 2023, the entireties of each being incorporated by reference herein.

**TECHNICAL FIELD**

**[0002]** This disclosure relates to Roots-type devices used in expander and compressor applications.

**BACKGROUND**

**[0003]** Roots-type expanders utilize the energy in the fluid stream applied to the rotor surfaces to create rotational work. By increasing the time within the device, the pressure differential applied to the rotors can improve the efficiency of the device. One way to increase this “time” is to twist the rotors more than the ideal twist. However, conventional methods of designing rotors of Roots-type expanders have limitations of hardware constraints. Improvements are desired.

**SUMMARY**

**[0004]** In general terms, this disclosure is directed to a volumetric fluid expander. Various aspects are described in this disclosure, which include, but are not limited to, the following aspects.

**[0005]** In one aspect of the disclosure, a volumetric fluid expander is provided to generate useful work by expanding a working fluid. In one application, the volumetric fluid expander can be utilized to recover waste energy from a power plant, such as waste heat energy from a fuel cell or an internal combustion engine. The power plant may be provided in a vehicle or may be provided in a stationary application such as could be the case when the power plant is used as a generator. In one possible configuration and by non-limiting example, the volumetric fluid expander is employed in an exhaust gas recirculation system of an internal combustion engine.

**[0006]** In one example, the working fluid is all or part of the exhaust gas stream from an internal combustion engine or a fuel cell. In another example, the working fluid is separate from and heated by a waste heat stream from an internal combustion engine or a fuel cell, such as is disclosed in International Publication Number WO 2013/130774, which is incorporated herein by reference. WO 2013/130774 discloses that the working fluid can be used in a Rankine cycle where the working fluid may be a solvent such as ethanol, n-pentane, or toluene.

**[0007]** A Roots-type device can include a housing assembly having a first opening and a second opening in fluid communication with an internal cavity; a pair of identical rotors oppositely arranged within the housing internal cavity, each of the pair of rotors having a longitudinal axis and a plurality of lobes, each of the lobes defining an end face extending between a first longitudinal side of the rotor lobe and a second longitudinal side of the rotor lobe; and a recess port defined within the housing assembly and being axially spaced from the end faces of the rotor lobes, the recess port placing the first longitudinal side of one of the rotor lobes in

fluid communication with the second longitudinal side of the rotor lobe such that the housing first opening is placed in fluid communication with the housing second opening.

**[0008]** In some examples, the housing assembly includes a main housing and a bearing plate secured to the main housing, and wherein the recess port is defined within the bearing plate.

**[0009]** In some examples, the end face of at least one rotor lobe faces the recess port in all rotational angles of the rotors.

**[0010]** In some examples, each of the pair of rotors has a twist angle that is less than or equal to an ideal twist angle of the rotors defined without the presence of the recess port.

**[0011]** In some examples, each of the pair of rotors has three lobes.

**[0012]** In some examples, the rotors are located axially between the housing first opening and the recess port.

**[0013]** In some examples, the pair of rotors are each supported by rotatable shafts located between the housing second opening and the recess port.

**[0014]** In some examples, the pair of rotors are each supported by shafts having longitudinal axes aligned along a first longitudinal plane, wherein a housing outlet is located on a first side of the first longitudinal plane, and wherein the recess port is located on a second side of the first longitudinal plane.

**[0015]** In some examples, the first opening is orthogonal to the longitudinal axes of the rotors.

**[0016]** In some examples, the second opening is parallel to the longitudinal axes of the rotors.

**[0017]** A Roots-type device can include a pair of rotors and a housing assembly within which the rotors are disposed, the housing assembly having a first opening and a second opening, and having a recess port placing the housing first opening in fluid communication with the housing second opening.

**[0018]** In some examples, the recess port is located at a first axial end of the pair of rotors.

**[0019]** In some examples, the recess port defines a leak path around an axial end of at least one lobe of the pair of rotors in at least some rotational positions of the pair of rotors.

**[0020]** In some examples, the recess port places a first longitudinal side of one of the rotor lobes in fluid communication with a second longitudinal side of the rotor lobe.

**[0021]** In some examples, the housing assembly includes a main housing and a bearing plate secured to the main housing, and wherein the recess port is defined within the bearing plate.

**[0022]** In some examples, an end face of at least one lobe of the pair of rotors faces the recess port in all rotational angles of the rotors.

**[0023]** In some examples, each of the pair of rotors has a twist angle that is less than or equal to an ideal twist angle of the rotors defined without the presence of the recess port.

**[0024]** In some examples, each of the pair of rotors has three lobes.

**[0025]** In some examples, the rotors are located axially between the housing first opening and the recess port.

**[0026]** In some examples, the pair of rotors are each supported by rotatable shafts located between the housing second opening and the recess port.

**[0027]** In some examples, the pair of rotors are each supported by shafts having longitudinal axes aligned along

a first longitudinal plane, wherein a housing outlet is located on a first side of the first longitudinal plane, and wherein the recess port is located on a second side of the first longitudinal plane.

**[0028]** In some examples, the first opening is orthogonal to the longitudinal axes of the rotors.

**[0029]** In some examples, the second opening is parallel to the longitudinal axes of the rotors.

**[0030]** A bearing plate for a Roots-type device can include a main body extending along a longitudinal axis from a first side to a second side; a pair of cavities for supporting bearing and seal assemblies, the cavities extending between the first and second sides of the main body; a primary surface at least partially defining the first side and being orthogonal to the longitudinal axis; and a recess area at least partially defining the first side and being axially recessed from the primary surface in a direction towards the second side, the recess area being configured to provide a leak path for the Roots-type device.

**[0031]** In some examples, the recess area is located entirely on a first side of a plane extending centrally through the pair of cavities and parallel to the longitudinal axis.

**[0032]** In some examples, the recess area extends to an outer edge of the main body.

**[0033]** In some examples, the main body includes a second recess area at least partially defining the first side and being axially recessed from the primary surface in a direction towards the second side, the second recess area being located entirely on a second side of the plane.

**[0034]** In some examples, the recess area has a V-shape.

**[0035]** A method for retrofitting a supercharger for an expander application can include providing a supercharger having a pair of rotors and a housing assembly within which the rotors are disposed, the housing assembly having a first opening and a second opening; removing a first bearing plate of the supercharger; and installing a second bearing plate onto the supercharger, the second bearing plate including a recess port placing the housing first opening in fluid communication with the housing second opening.

**[0036]** A Roots-type device can include a housing assembly having a first opening and a second opening in fluid communication with an internal cavity; a pair of identical rotors oppositely arranged within the internal cavity, each of the pair of rotors having a longitudinal axis and a plurality of lobes, wherein the rotors are intermeshed and, when rotating, define a rotor mesh axial lead velocity; and an inlet nozzle structure in fluid communication with the first opening, the inlet nozzle structure tapering towards the first opening and being configured such that a nozzle velocity of a working fluid passing through the inlet nozzle structure is at least equal to the rotor mesh axial lead velocity.

**[0037]** In some examples, the inlet nozzle structure is oriented generally parallel to the longitudinal axis.

**[0038]** In some examples, the inlet nozzle structure is oriented at an oblique angle to the longitudinal axis.

**[0039]** In some examples, the cross-sectional area of the nozzle structure decreases by at least 20 percent.

**[0040]** In some examples, a volumetric flow rate through the inlet nozzle structure is increased by at least double.

**[0041]** In some examples, each of the rotors includes four lobes.

**[0042]** In some examples, the nozzle velocity is greater than the rotor mesh axial lead velocity.

**[0043]** In some examples, the nozzle velocity is at least 1.1 times the rotor mesh axial lead velocity.

**[0044]** In some examples, the nozzle velocity is at least 1.6 times the rotor mesh axial lead velocity.

**[0045]** Additional objects and advantages will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the teachings presented herein. The objects and advantages will also be realized and attained by means of the elements and combinations particularly pointed out in the appended claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the claimed invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0046]** FIG. 1 is a perspective view of a Roots-type device having features that are examples of aspects in accordance with the principles of the present disclosure.

**[0047]** FIG. 2 is a second perspective view of the Roots-type device shown in FIG. 1.

**[0048]** FIG. 3 is a top view of the Roots-type device shown in FIG. 1.

**[0049]** FIG. 4 is a bottom view of the Roots-type device shown in FIG. 1.

**[0050]** FIG. 5 is a first side view of the Roots-type device shown in FIG. 1.

**[0051]** FIG. 6 is a second side view of the Roots-type device shown in FIG. 1.

**[0052]** FIG. 7 is a first end view of the Roots-type device shown in FIG. 1.

**[0053]** FIG. 8 is a second end view of the Roots-type device shown in FIG. 1.

**[0054]** FIG. 9 is a first cross-sectional view of the Roots-type device shown in FIG. 1, taken along line 9-9 in FIG. 7.

**[0055]** FIG. 10 is a second cross-sectional view of the Roots-type device shown in FIG. 1, taken along line 10-10 in FIG. 7.

**[0056]** FIG. 11 is a third cross-sectional view of the Roots-type device shown in FIG. 1, taken along line 11-11 in FIG. 5.

**[0057]** FIG. 12 is a partial perspective view of the Roots-type device shown in FIG. 1, illustrating a leak path within the device.

**[0058]** FIG. 13 is a perspective view of a bearing plate of the Roots-type device shown in FIG. 1.

**[0059]** FIG. 14 is a second perspective view of the bearing plate shown in FIG. 13.

**[0060]** FIG. 15 is a first end view of the bearing plate shown in FIG. 13.

**[0061]** FIG. 16 is a second end view of the bearing plate shown in FIG. 13.

**[0062]** FIG. 17 is a cross-sectional view of the bearing plate shown in FIG. 13, taken along line 17-17 in FIG. 16.

**[0063]** FIG. 18 is a perspective view of a rotor of the Roots-type device shown in FIG. 1.

**[0064]** FIG. 19 is an end view of the rotor shown in FIG. 18.

**[0065]** FIG. 20 is a perspective view of a second example of a rotor usable with the Roots-type device shown in FIG. 1.

**[0066]** FIG. 21 is an end view of the rotor shown in FIG. 20.

[0067] FIG. 22 is a schematic cross-sectional view of the Roots-type expander shown in FIG. 1.

[0068] FIG. 23 is a schematic perspective view of a variation of the Roots-type expander shown in FIG. 1.

[0069] FIG. 24 is a schematic cross-sectional side view of variation of the Roots-type expander shown in FIG. 1.

[0070] FIG. 25 is a side view of a second embodiment of a volumetric fluid expander having features that are examples of aspects in accordance with the principles of the present disclosure.

[0071] FIG. 26 is a cross-sectional side view of the volumetric fluid expander shown in FIG. 25.

[0072] FIG. 27 is a cross-sectional side view of a portion of the fluid expander shown in FIG. 25.

[0073] FIG. 28 is a top view of the portion of the fluid expander shown in FIG. 27.

[0074] FIG. 29 is a perspective view of the portion of the fluid expander shown in FIG. 27.

[0075] FIG. 30 is a perspective view of the rotors of the fluid expander shown in FIG. 25.

[0076] FIG. 31 is a schematic perspective view of the volumetric fluid expander shown in FIG. 25.

[0077] FIG. 32 is a schematic showing geometric parameters of the rotors of the volumetric fluid expanders shown in FIGS. 1, 23, and 24.

#### DETAILED DESCRIPTION

[0078] This disclosure is related to energy recovery devices for use in multiple applications. In one, the disclosed energy recovery devices are usable in vehicle power plant applications where waste heat energy from the vehicle power plant is captured and returned to the power plant. In some examples, the working fluid used by the expander is a compressible fluid such as air. The disclosed energy recovery devices can be used in other applications as well, for example, in marine and agricultural industries.

[0079] Referring to FIGS. 1-12 and 23-25, a Roots-type device 20, also called energy recovery device, in accordance with the present teachings is shown. FIGS. 1-12 present the Roots-type device 20 in a physical embodiment, while FIGS. 23-25 present the Roots-type device 20 in schematic cross-sectional form.

[0080] In one aspect, the Roots-type device 20 includes a main housing 102 that defines an internal cavity or first working fluid passageway 106 extending between a first opening 108 and a second opening 110. Disposed within the working fluid passageway 106 is a pair of intermeshed rotors 30, 32 extending between end faces 30a, 30b and 32a, 32b. In the example presented, the rotors 30, 32 are three-lobe rotors with lobes 30-1, 30-2, 30-3 and 32-1, 32-2, 32-3, such as the rotor 30, 32 shown in isolation at FIGS. 18 and 19. As presented, the number of lobes is the same for each rotor 30 and 32. This is in contrast to the construction of typical rotary screw devices and other similarly configured rotating equipment which have a dissimilar number of lobes (e.g., a male rotor with “n” lobes and a female rotor with “n+1” lobes). Furthermore, one of the distinguishing features of the Roots-type device 20 is that the rotors 30 and 32 are identical, wherein the rotors 30, 32 are oppositely arranged so that, as viewed from one axial end, the lobes of one rotor are twisted clockwise while the lobes of the meshing rotor are twisted counter-clockwise. Other configurations are possible, such as the four-lobe rotor 30, 32 schematically presented at FIGS. 20 and 21.

[0081] In the example presented, the first opening 108 is disposed generally parallel to a longitudinal axis X of the energy recovery device while the second opening 110 is disposed generally orthogonally to the longitudinal axis X. Other opening configurations are possible. In one example, the Roots-type device 20 is configured such that a working fluid 12 flows from the first opening 108, which can be characterized as an inlet 108, to the second opening 110, which can be characterized as an outlet 110. The Roots-type device 20 may be operated or configured such that flow in the opposite direction occurs as well. In some examples, the working fluid is a compressible fluid, such as atmospheric air or engine exhaust. In some applications, the Roots-type device 20 operates as an expander in which the working fluid flows through the passageway 106 to impart rotational energy onto the rotors 30, 32 which can then be output by the device 20. In some applications, the Roots-type device 20 operates as a compressor, such as in a supercharger application, in which the rotors 30, 32 are rotated to generate and deliver a flow of the working fluid. In some applications, the same Roots-type device 20 is selectively operable in both an expander mode and a compressor mode.

[0082] In one aspect, and as most easily viewed at FIGS. 9 and 10, each of the rotors 30, 32 are respectively mounted to rotor shafts 38, 40. In the example shown, the shaft 38 has an extension portion 38a such that power can be transferred to and/or from the Roots-type device 20 via attached pulleys, gears, or the like. In the schematic example presented at FIG. 25, a pulley or gear 200 is mounted to shaft 38 and operatively connected to an input/output location 16 via a belt, chain, or gear set 202, such as a planetary gear set. The input/output location 16 can be any machine, device, or system capable of receiving, transferring, or generating energy such as a motor/generator or an internal combustion engine.

[0083] In one aspect, a timing gear 42, 44 is respectively mounted to each shaft 38, 40. The timing gears 42, 44 are intermeshed with each other to ensure that the rotors 30, 32 rotate synchronously such that interference between the rotors 30, 32 is avoided. Bearing and seal assemblies of a known type 46, 48 and 50, 52 are also provided at each shaft 38, 40 on opposite sides of the rotors 30, 32 to rotationally support the shafts 38, 40 and to ensure that the working fluid within the housing passageway 106 does not leak past the shafts 38, 40 as it exits the passageway 106. In the example shown, the bearing assemblies 46, 48 are supported within cavities 70, 72 of a bearing plate 60 which is mounted to the housing 102. The bearing plate 60 forms an end surface of the internal cavity of the housing and passageway 106. The bearing assemblies 50, 52 are shown as being supported in recess or cavity portions of the housing 102.

[0084] The bearing plate 60, when removed, provides an opening through which the rotors 30, 32 can be installed and removed from the interior of the housing 102. The bearing plate 60, shown in isolation at FIGS. 13 to 17, is shown as including an interior face 62 facing the interior of the housing 102 and passageway 106. The interior face 62 includes a primary surface 64, a first recessed area 66, and a recess port 68. The primary surface 64 is located in close proximity to the end faces 30a, 32b of the rotors 30, 32 such that leakage between the primary surface 64 and the rotors 30, 32 is minimized as much as possible. The first recessed area 66 is recessed in an axial direction away from the end faces 30a, 32b of the rotors 30, 32 and is also open to the

second opening 110. Accordingly, the first recessed area 66 enlarges the area or volume through which the working fluid can enter or leave the passageway 106 and rotors 30, 32. The recess port 68, located opposite the first recessed area 66 and opening 110, which includes a first wall 68a parallel to the end faces 30a, 32a of the rotors 30, 32, is also recessed in an axial direction away from the end faces 30a, 32b of the rotors to create a gap 69 which is relatively larger than the gap between the end faces 30a, 32b and a bearing plate primary surface 64. The recess port 68 also includes a second wall 68b extending from the primary surface 64 to the first wall 68a. Accordingly, the second wall 68b extends in a direction that is generally orthogonal to the ends faces 39a, 32b and parallel to the length of the rotors 30, 32. In one aspect, the second wall 68b can be characterized as having a V-shape or V-type shape having a center that is closer to the longitudinal axis X in comparison to the ends of the second wall 68b. This shape is advantageous as the leak path created by the recess port, discussed in more detail below, is more consistently maintained as the height of the rotor lobes necessarily changes as they rotate across the recess port 68. Although the recess port 68 is shown as being integrated into the bearing plate 60, other configurations are possible. For example, the recess port 68 could be incorporated into a surface of the housing 102. In one aspect, the bearing plate 60 and main housing 102 can be characterized as being a housing assembly, while the recess port 68 can be characterized as being formed within the housing assembly. In one aspect, the recess port 68 can be characterized as being a metering port or orifice means. In one aspect, the housing 102, rotors 30, 32, and recess port 68 of the bearing plate 60 collectively define the cross-sectional area or orifice area that defines the leak path. This area is to be considered the area perpendicular to the fluid flow through the port which should be parallel to the end face of the rotor. The shape and size of the recess port 68 can be determined or optimized for a specific application. For example, the depth of the recess port 68 (i.e., the distance between first wall 38a and end faces 30a, 32b and defined by the width of the second wall 68b) can be adjusted to result in a desired orifice area. For example, if it is desired to have a compressor mode and an expander mode for the device 20, and the expander efficiency mode is more favorable, creating a leak path would favor this mode and the recess port 68 may be designed to be larger for an optimized leak. If the compressor mode is favored, then the recess port 68 and resulting leak path would be minimized to favor the compressor mode. Further, the pressure ratio and speed of the device 20 will also influence the cross-sectional area of the port.

[0085] During operation, as an individual rotor lobe 30-1, 30-2, 30-3 and 32-1, 32-2, 32-3 rotates across the recess port 68, a passageway 107 is created that extends from one longitudinal side (e.g., side A) of the lobe, around the end face 30a, 32b of the lobe and into the recess port 68, and to the other longitudinal side (e.g., side B) of the lobe. The pathway is schematically depicted at FIG. 25 and in partial view provided at FIG. 12. By use of the term cross or crosses, it is meant that the end face of a lobe is exposed to and faces the recess port such that fluid communication exists at least between one side of the lobe and the recess port. By use of the term fully cross or fully crosses, it is meant that the end face of a lobe is exposed to and faces the recess port such that fluid communication exists between both sides of the lobe and the recess port.

[0086] When a rotor lobe fully crosses the recess port 68, one side of the lobe is in fluid communication with the opening 108 while the other side of the lobe is in fluid communication with the opening 110. As such, the recess port functions to create the orifice or passageway 107 extending between the openings 108, 110. In the example shown, the recess port 68 is shaped such that at least one rotor lobe 30-1, 30-2, 30-3 and 32-1, 32-2, 32-3 of one of the rotors 30, 32 fully crosses the recess port 68 at all rotational angles such that the passageway 107 is continuously maintained. The passageway 107 can thus be characterized as an orifice or a strategic leak path. In some rotational angles, at least one lobe 30-1, 30-2, 30-3 of rotor 30 and at least one lobe 32-1, 32-2, 32-3 of rotor 32 cross the recess port 68 at the same time. In some rotational angles of the rotor 30, none of the lobes 30-1, 30-2, 30-3 of rotor 30 cross the recess port 68. In some rotational angles of the rotor 32, none of the lobes 32-1, 32-2, 32-3 of rotor 32 cross the recessed port 68. Other configurations are possible.

[0087] When the device 20 is operated as an expander, the creation of a strategic leak path 107 is advantageous in that the time or duration that the working fluid is exposed to the rotors 30, 32 is increased. This allows additional working fluid to expand within the outlet to create a greater pressure drop which results in additional rotational work being imparted to the rotors 30, 32. Stated in other terms, the disclosed design advantageously allows the fluid velocity (i.e., fluid kinetic energy) of the working fluid to remain higher and to generate rotation within the energy recovery device. The increased fluid velocity flow assists in the conversion of energy in the fluid stream into the rotor's rotation by imparting an additional moment on the rotor shafts. The strategic leak path 107, enabled by the recess port 68, also ensures additional expansion occurs in the outlet ensuring the working fluid 12 continues to transfer out of the device.

[0088] Another advantage is that the recess port 68 allows for a strategic leak path 107 to be created without requiring an increase of the twist angle of the rotors 30, 32 above the ideal twist angle, as would otherwise be necessary to ensure the openings 108, 110 remain in fluid communication with each other but for the presence of the recess port 68. For reference, the twist angle is known to those skilled in the art to be the angular displacement of the lobe, in degrees, which occurs in "traveling" the length L of the lobe from the rearward end of the rotor to the forward end of the rotor. A further discussion on the concepts of twist angle can be found at U.S. Pat. No. 7,488,164, the entirety of which is incorporated by reference herein. An illustration of the twist angle and related parameters is also provided at FIG. 32. The "ideal twist" is the maximum twist angle through which the rotor 30, 32 can twist without causing a leak will occur between the inlet and the outlet. Accordingly, rotors designed for a supercharger application having an ideal twist angle or less can be readily adapted for use in an expander application by providing the recess port 68 in the bearing plate 60 or in a modified housing 102. In one example, a supercharger can be retrofitted for expander operation by replacing an existing bearing plate with a bearing plate 60 of the type disclosed herein having a recess port 68. Even in cases where the rotors 30, 32 are provided with a twist angle deviating from the ideal twist angle, the recess port 68 reduces the incremental deviation of the twist angle that would otherwise be expected without the presence of the

recess port 68, as the fluid will advantageously remain in contact with the rotors 30, 32 within the outlet for much longer as the fluid 12 is allowed to expand.

[0089] Other configurations of the Roots-type device 20 are possible. For example, as schematically illustrated at FIG. 23, the device 20 can be provided with a differently configured recess port which can also be characterized as a metering arrangement 68 that spans the inlet and outlet ends. As shown, there is a metering port 68 at the inlet end and a metering port 68 at the end opposite end of the inlet, wherein the two metering ports 68 create the crossover to the inlet and outlet, configured such that the recess port 68, connecting the inlet 108 and the outlet 110, extends along the length of the rotors 30, 32. As shown at FIG. 23, each rotor 30, 32 is provided with four lobes having 220 degrees of twist.

[0090] Yet another variation of the Roots-type device 20 is presented at FIG. 24 in which a nozzle section 24d is provided at the inlet 108 that tapers from a first dimension w2, defining a first cross-sectional area, to a second dimension w3, at least partially defining a second cross-sectional area that is less than the first cross-sectional area. The nozzle section 24d, described in further detail with respect to the embodiment shown at FIGS. 25 to 32, operates to accelerate the velocity of the fluid 12 such that additional efficiencies of the Roots-type device 20 can be realized.

[0091] Incorporating a recess port 68 and the nozzle section 24d into the same Roots-type device 20, as shown at FIG. 24, can result in additional operational efficiencies and power output.

[0092] FIGS. 25 to 32 present another example of a Roots-type device 20 also including a nozzle section 24d in a housing configuration with a modified inlet and outlet, in comparison to those shown at FIGS. 1 to 24. Although not illustrated at FIGS. 25 to 32, the Roots-type device 20 of these figures can be provided with a recess port that creates a bypass passageway around the ends of the rotors to interconnect the device inlet and outlet. As noted previously, the following description of the nozzle section 24d is applicable to the nozzle section 24d schematically shown at FIG. 24.

[0093] With continued reference to FIGS. 24 to 32, Roots-type device 20 has a housing 22 with a fluid inlet structure 24 and a fluid outlet structure 26 through which a working fluid 12 undergoes a pressure drop to transfer energy to an output shaft 38. The inlet structure 24 is configured to admit working fluid 12-1 at a first pressure whereas the outlet structure 26 is configured to discharge working fluid 12-2 at a second pressure lower than the first pressure. The output shaft 38 is driven by synchronously connected first and second interleaved counter-rotating rotors 30, 32 which are disposed in a cavity 28 of the housing 22. Each of the rotors 30, 32 has lobes that are twisted or helically disposed along the length of the rotors 30, 32. Upon rotation of the rotors 30, 32, the lobes at least partially seal the fluid 12-1 against an interior side of the housing at which point expansion of the fluid 12-1 only occurs to the extent allowed by leakage which represents an inefficiency in the system. In contrast to some Roots-type devices that change the volume of the fluid when the fluid is sealed, the volume defined between the lobes and the interior side of the housing 22 of device 20 is constant as the fluid 12-1 traverses the length of the rotors 30, 32. Accordingly, the Roots-type device 20 is referred to as a “volumetric device” as the sealed or partially sealed fluid volume does not change.

[0094] As additionally shown schematically at FIG. 31, each rotor 30, 32 has four lobes, 30-1, 30-2, 30-3, and 30-4 in the case of the rotor 30, and 32-1, 32-2, 32-3, and 32-4 in the case of the rotor 32. Although four lobes are shown for each rotor 30 and 32, each of the two rotors may have any number of lobes that is equal to or greater than two, for example three lobes. Additionally, the number of lobes is the same for each rotor 30 and 32. This is in contrast to the construction of typical rotary screw devices and other similarly configured rotating equipment which have a dissimilar number of lobes (e.g., a male rotor with “n” lobes and a female rotor with “n+1” lobes). Furthermore, one of the distinguishing features of the Roots-type device 20 is that the rotors 30 and 32 are identical, wherein the rotors 30, 32 are oppositely arranged so that, as viewed from one axial end, the lobes of one rotor are twisted clockwise while the lobes of the meshing rotor are twisted counter-clockwise. Accordingly, when one lobe of the rotor 30, such as the lobe 30-1, is leading with respect to the inlet structure 24, a lobe of the rotor 32, such as the lobe 30-2, is trailing with respect to the inlet structure 24, and, therefore with respect to a stream of the high-pressure fluid 12-1.

[0095] As shown, the first and second rotors 30, 32 are fixed to respective rotor shafts, the first rotor being fixed to the output shaft 38 and the second rotor being fixed to a shaft 40. Each of the rotor shafts 38, 40 is mounted for rotation on sets of bearings 43, 45 about an axis X1, X2, respectively. It is noted that axes X1 and X2 are generally parallel to each other.

[0096] The first and second rotors 30, 32 are interleaved and continuously meshed for unitary rotation with each other. With renewed reference to FIG. 1, the expander 20 also includes meshed timing gears 42 and 44, wherein the timing gear 42 is fixed for rotation with the rotor 30, while the timing gear 44 is fixed for rotation with the rotor 32. The timing gears 42, 44 are also configured to maintain the relative position of the rotors 30, 32 such that contact between the rotors is entirely prevented which could cause extensive damage to the rotors 30, 32. Rather, a close tolerance between the rotors 30, 32 is maintained during rotation by the timing gears 42, 44. As the rotors 30, 32 are non-contacting, a lubricant in the fluid 12 is not required for operation of the Roots-type device 20, in contrast to typical rotary screw devices and other similarly configured rotating equipment having rotor lobes that contact each other.

[0097] The output shaft 38 is rotated by the working fluid 12 as the fluid undergoes expansion from the higher first pressure working fluid 12-1 to the lower second pressure working fluid 12-2. As may additionally be seen in FIGS. 1, 2, and 7, the output shaft 38 extends beyond the boundary of the housing 22. Accordingly, the output shaft 38 is configured to capture the work or power generated by the expander 20 during the expansion of the fluid 12 that takes place in the rotor cavity 28 between the inlet structure 24 and the outlet structure 26 and transfer such work as output torque from the expander 20. Although the output shaft 38 is shown as being operatively connected to the first rotor 30, in the alternative, the output shaft 38 may be operatively connected to the second rotor 32. The output shaft 38 can be coupled to an engine such that the energy from the exhaust can be recaptured.

[0098] In one aspect of the geometry of the expander 20, each of the rotor lobes 30-1 to 30-4 and 32-1 to 32-4 has a lobe geometry in which the twist of each of the first and

second rotors **30** and **32** is constant along their substantially matching length **L**. As shown schematically at FIG. **8**, one parameter of the lobe geometry is the helix angle **HA**. By way of definition, it should be understood that references hereinafter to “helix angle” of the rotor lobes is meant to refer to the helix angle at the pitch diameter **PD** (or pitch circle) of the rotors **30** and **32**. The term pitch diameter and its identification are well understood to those skilled in the gear and rotor art and will not be further discussed herein. As used herein, the helix angle **HA** can be calculated as follows: Helix Angle (**HA**)= $(180/\pi \cdot \arctan(\text{PD}/\text{Lead}))$ , wherein: **PD**=pitch diameter of the rotor lobes; and **Lead**=the lobe length required for the lobe to complete 360 degrees of twist. It is noted that the **Lead** is a function of the twist angle and the length **L1**, **L2** of the lobes **30**, **32**, respectively. The twist angle is known to those skilled in the art to be the angular displacement of the lobe, in degrees, which occurs in “traveling” the length of the lobe from the rearward end of the rotor to the forward end of the rotor. In some examples, the twist angle is about 120 degrees, although the twist angle may be fewer or more degrees.

[0099] In another aspect of the expander geometry, the inlet structure **24** includes an inlet angle **24-1**, as can be seen schematically at FIG. **26**. In one example, the inlet angle **24-1** is defined as the general or average angle of an inner surface **24a** of the inlet structure **24**, for example an anterior inner surface. In one example, the inlet angle **24-1** is defined as the angle of the general centerline **CL-1** of the inlet structure **24**, for example as shown at FIG. **2**. In one example, the inlet angle **24-1** is defined as the general resulting direction of the fluid **12-1** entering the rotors **30**, **32** due to contact with the anterior inner surface **24a**, as can be seen at FIG. **26**. As shown, the inlet angle **24-1** is neither perpendicular nor parallel to the rotational axes **X1**, **X2** of the rotors **30**, **32**. Accordingly, the anterior inner surface **24a** of the inlet structure **24** causes a substantial portion of the fluid **12-1** to be shaped in a direction that is at an oblique angle with respect to the rotational axes **X1**, **X2** of the rotors **30**, **32**, and thus generally parallel to the inlet angle **24-1**.

[0100] Furthermore, and as shown in FIGS. **26** to **29**, the inlet structure **24** may be shaped such that the fluid **12-1** is directed to first axial ends of the rotors **30**, **32** and directed to the rotor lobe leading and trailing surfaces (discussed below) from a lateral direction. However, it is to be understood that the inlet angle **24-1** may be generally parallel or generally perpendicular to axes **X1**, **X2**, although an efficiency loss may be anticipated for certain rotor configurations. For example, as shown at FIG. **24**, the inlet angle **24-1** is generally parallel to axes **X1**, **X2**. By use of the term generally parallel, it is meant to refer angles that are within 10 to 15 degrees of each other. Furthermore, and as discussed in more detail later, it is noted that the inlet structure **24** may be shaped to narrow towards an inlet opening **24b**, as shown in FIGS. **26** and **28**.

[0101] In another aspect of the expander geometry, the outlet structure **26** includes an outlet angle **26-1**, as can be seen schematically at FIG. **26**. In one example, the outlet angle **26-1** is defined as the general or average angle of an inner surface **26a** of the outlet structure **26**. In one example, the outlet angle **26-1** is defined as the angle of the general centerline **CL-2** of the outlet structure **26**, for example as shown at FIGS. **26** and **27**. In one example, the outlet angle **26-1** is defined as the general resulting direction of the fluid **12-2** leaving the rotors **30**, **32** due to contact with the inner

surface **26a**, as can be seen at FIG. **26**. As shown, the outlet angle **26-1** is neither perpendicular nor parallel to the rotational axes **X1**, **X2** of the rotors **30**, **32**. Accordingly, the inner surface **26a** of the outlet structure **26** receives the leaving fluid **12-2** from the rotors **30**, **32** at an oblique angle which can reduce backpressure at the outlet structure **26**. In one example, the inlet angle **24-1** and the outlet angle **26-1** are oblique with respect to each other, as is shown in the drawings. The inlet angle **24-1** and the outlet angle **26-1** can be generally equal or parallel, in alternative arrangements.

[0102] It is to be understood that the outlet angle **26-1** may be generally perpendicular to axes **X1**, **X2**, as is shown schematically at FIG. **24**. As configured, the orientation and size of the outlet structure **26-1** are established such that the leaving fluid **12-2** can evacuate each rotor cavity **28** as easily and rapidly as possible so that backpressure is reduced as much as possible. The output power of the shaft **38** is maximized to the extent that backpressure caused by the outlet can be minimized such that the fluid can be rapidly discharged. The efficiency of the expander **20** can be optimized by coordinating the geometry of the inlet angle **24-1** and the geometry of the rotors **30**, **32**. For example, the helix angle **HA** of the rotors **30**, **32** and the inlet angle **24-1** can be configured together in a complementary fashion. Because the inlet structure **24** introduces the fluid **12-1** to both the leading and trailing faces of each rotor **30**, **32**, the fluid **12-1** performs both positive and negative work on the expander **20**.

[0103] To illustrate, FIG. **31** shows that lobes **30-1**, **30-4**, **32-1**, and **32-2** are each exposed to the fluid **12-1** through the inlet structure opening **24b**. Each of the lobes has a leading surface and a trailing surface, both of which are exposed to the fluid at various points of rotation of the associated rotor. The leading surface is the side of the lobe that is forward most as the rotor is rotating in a direction **R1**, **R2** while the trailing surface is the side of the lobe opposite the leading surface. For example, rotor **30** rotates in direction **R1** thereby resulting in the side **30-1a** being the leading surface of lobe **30-1** and side **30-1b** being the trailing surface. As rotor **32** rotates in a direction **R2** which is opposite direction **R1**, the leading and trailing surfaces are mirrored such that side **32-2a** is the leading surface of lobe **32-2** while side **32-2b** is the trailing surface.

[0104] In generalized terms, the fluid **12-1** impinges on the trailing surfaces of the lobes as they pass through the inlet structure opening **24b** and positive work is performed on each rotor **30**, **32**. By use of the term positive work, it is meant that the fluid **12-1** causes the rotors to rotate in the desired direction: direction **R1** for rotor **30** and direction **R2** for rotor **32**. As shown, fluid **12-1** will operate to impart positive work on the trailing surface **32-2b** of lobe **32-2**, for example on surface portion **47**. The fluid **12-1** is also imparting positive work on the trailing surface **30-1b** of lobe **30-1**, for example of surface portion **46**. However, the fluid **12-1** also impinges on the leading surfaces of the lobes, for example surfaces **30-1a** and **32-1a**, as they pass through the inlet structure opening **24b** thereby causing negative work to be performed on each rotor **30**, **32**. By use of the term negative work, it is meant that the fluid **12-1** causes the rotors to rotate opposite to the desired direction, **R1**, **R2**.

[0105] Accordingly, it is desirable to shape and orient the rotors **30**, **32** and to shape and orient the inlet structure **24** such that as much of the fluid **12-1** as possible impinges on the trailing surfaces of the lobes with as little of the fluid

12-1 impinging on the on the leading surfaces of the lobes such that the highest net positive work can be performed by the expander 20.

[0106] In the example shown, the inlet structure 24 includes a first inlet section 24c and a nozzle section 24d located between the rotors 30, 32 and the first inlet section 24c. In the example shown, the inlet section 24c has a

in further performance gains. In one example, as outlined in Table 1 below, an expander, having a displacement of 644 cc (cubic centimeters) and a rotor lead of 200 m, is provided such that dimension w1 is 89 mm, dimension w2 is 76 mm, and dimension w3 is 60 mm. As such, the nozzle section 24d decreases in cross-sectional area by over 20 percent with a corresponding increase in fluid velocity.

TABLE 1

Expander displacements 644 cc Rotor lead 200 mm										
RPM										
		2000	4000	6000	8000	10000	12000	14000	RPM	
		6.67	13.33	20.00	26.67	33.33	40.00	46.67	m/s	
Rotor axial lead velocity										
Volume flow rate		0.0215	0.0429	0.0644	0.0859	0.1073	0.1288	0.1503	m <sup>3</sup> /s	
Diameter of flow section	89	0.0062	3.45	6.90	10.35	13.80	17.25	20.70	24.15	m/s
	76	0.0045	4.73	9.46	14.20	18.93	23.66	28.39	33.12	
section	60	0.0028	7.59	15.18	22.78	30.37	37.96	45.55	53.15	
										Velocity in port

generally constant diameter or dimension w1. In some examples, the inlet section 24c can be tapered. In the example shown, a transition section 24e is located between the first inlet section 24c and the nozzle section 24d and includes a radiused or tapering section transitioning to a diameter or dimension w2.

[0107] As shown, the nozzle section 24d tapers from the diameter or dimension w2 proximate the first inlet section 24c to a diameter or dimension w3 proximate the rotors 30, 32. In some examples, the taper between w2 and w3 results in at least a ten percent decrease in cross-sectional area of the nozzle section 24d. In the example shown, the nozzle section 24d includes a frustoconical taper such that the sidewalls of the nozzle section 24d are straight and define a continuous, gradual taper, as is shown in the drawings. However, the nozzle section 24d may be provided with a taper that is curved in cross-section. In the example shown, and as most easily seen at FIGS. 27 to 29, the first inlet section 24c and the nozzle section 24d each have a circular cross-sectional shape. However, other cross-sectional shapes are possible, such as oval, elliptical, rectangular, and obround shapes. The nozzle section 24d can also taper in a non-symmetrical manner, for example, wherein only one side of the nozzle section 24d forms the tapering cross-section such as is schematically shown at FIG. 24 wherein the nozzle section 24d is also arranged to direct fluid flow 12-1 into the ends of the rotors 30, 32.

[0108] In one aspect, the inlet velocity VN of the fluid 12-1 leaving the nozzle section 24d and entering the rotors 30, 32 should at least equal to the rotor mesh axial lead velocity of the rotors 30, 32 for best energy conversion. As schematically shown at FIG. 4, the axial lead velocity VL is a well-known parameter in Roots-type devices and may also be referred to as the linear velocity of the lobe mesh. This parameter represents the speed with which the V-shape defined between the overlapping lobes of the intermeshed rotors 30, 32 travels in a longitudinal direction (i.e., parallel with the longitudinal axis X). The axial lead velocity is further described and shown in U.S. Pat. No. 7,788,164, which is incorporated herein by reference. In some applications, increasing the twist angle of the rotors 30, 32 results

[0109] As can be seen in Table 1, the nozzle section 24d increases the rotor axial lead velocity by over double throughout all operating rotational speeds of the rotors, thereby increasing the overall efficiency of the expander. As a result, the velocity in port value (VN) ranges from 7.59 m/s to 53.15 m/s and always exceeds the rotor axial lead velocity (VL) which ranges from 6.67 m/s to 46.67 m/s over the entire operating range of 2,000 to 14,000 rpm of the rotors. In the particular example shown, the nozzle velocity VN is about 1.1 times the rotor axial lead velocity VL. However, in some applications, such as lower pressure applications, the nozzle velocity VN can further exceed the rotor axial lead velocity VL. For example, the nozzle velocity VN can be about 1.6 times the rotor axial lead velocity VL, or more.

[0110] Other implementations will be apparent to those skilled in the art from consideration of the specification and practice of the examples and teachings presented herein. It is intended that the specification and examples be considered as exemplary only, with the true scope of the invention being indicated by the following claims.

#### 1. A Roots-type device comprising:

- a housing assembly having a first opening and a second opening in fluid communication with an internal cavity;
- a pair of identical rotors oppositely arranged within the internal cavity, each of the pair of rotors having a longitudinal axis and a plurality of lobes, each of the lobes defining an end face extending between a first longitudinal side of the lobe and a second longitudinal side of the lobe; and
- a recess port defined within the housing assembly and being axially spaced from the end faces of the lobes, the recess port placing the first longitudinal side of one of the lobes in fluid communication with the second longitudinal side of the lobe such that the first opening is placed in fluid communication with the second opening.

2. The Roots-type device of claim 1, wherein the housing assembly includes a main housing and a bearing plate secured to the main housing, and wherein the recess port is defined within the bearing plate.



3. The Roots-type device of claim 1, wherein the end face of at least one lobe faces the recess port in all rotational angles of the rotors.

4. The Roots-type device of claim 1, wherein each of the pair of rotors has a twist angle that is less than or equal to an ideal twist angle of the rotors defined without the presence of the recess port.

5. The Roots-type device of claim 1, wherein each of the pair of rotors has at least three lobes.

6. The Roots-type device of claim 1, wherein the rotors are located axially between the first opening and the recess port.

7. The Roots-type device of claim 1, wherein the pair of rotors are each supported by rotatable shafts located between the second opening and the recess port.

8. The Roots-type device of claim 1, wherein the pair of rotors are each supported by shafts having longitudinal axes aligned along a first longitudinal plane, wherein a housing outlet is located on a first side of the first longitudinal plane, and wherein the recess port is located on a second side of the first longitudinal plane.

9. The Roots-type device of claim 8, wherein the first opening is orthogonal to longitudinal axes of the rotors.

10. The Roots-type device of claim 9, wherein the second opening is parallel to the longitudinal axes of the rotors.

11-39. (canceled)

40. The Roots-type device of claim 1, further comprising:

a) an inlet nozzle structure in fluid communication with the first opening, the inlet nozzle structure tapering towards the first opening and being configured such that a nozzle velocity of a working fluid passing through the inlet nozzle structure is at least equal to a rotor mesh axial lead velocity,

41. A bearing plate for a Roots-type device, the bearing plate comprising:

a) a main body extending along a longitudinal axis from a first side to a second side;  
b) a pair of cavities for supporting bearing and seal assemblies, the cavities extending between the first and second sides of the main body;  
c) a primary surface at least partially defining the first side and being orthogonal to the longitudinal axis; and

d) a first recessed area at least partially defining the first side and being axially recessed from the primary surface in a direction towards the second side, the recessed area being configured to provide a leak path for the Roots-type device.

42. The bearing plate of claim 41, wherein the first recessed area is located entirely on a first side of a plane extending centrally through the pair of cavities and parallel to the longitudinal axis.

43. The bearing plate of claim 41, wherein the first recessed area extends to an outer edge of the main body.

44. The bearing plate of claim 42, wherein the main body includes a second recessed area at least partially defining the first side and being axially recessed from the primary surface in a direction towards the second side, the second recessed area being located entirely on a second side of the plane.

45. The bearing plate of claim 41, wherein the first recessed area has a V-shape.

46. A Roots-type device comprising:

a) a housing assembly having a first opening and a second opening in fluid communication with an internal cavity;  
b) a pair of identical rotors oppositely arranged within the internal cavity, each of the pair of rotors having a longitudinal axis and a plurality of lobes, wherein the rotors are intermeshed and, when rotating, define a rotor mesh axial lead velocity; and  
c) an inlet nozzle structure in fluid communication with the first opening, the inlet nozzle structure tapering towards the first opening and being configured such that a nozzle velocity of a working fluid passing through the inlet nozzle structure is at least equal to the rotor mesh axial lead velocity.

47. The Roots-type device of claim 46, wherein the inlet nozzle structure is oriented generally parallel to the longitudinal axis.

48. The Roots-type device of claim 46, wherein the inlet nozzle structure is oriented at an oblique angle to the longitudinal axis.

49. The Roots-type device of claim 46, wherein a volumetric flow rate through the inlet nozzle structure is increased by at least double.

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