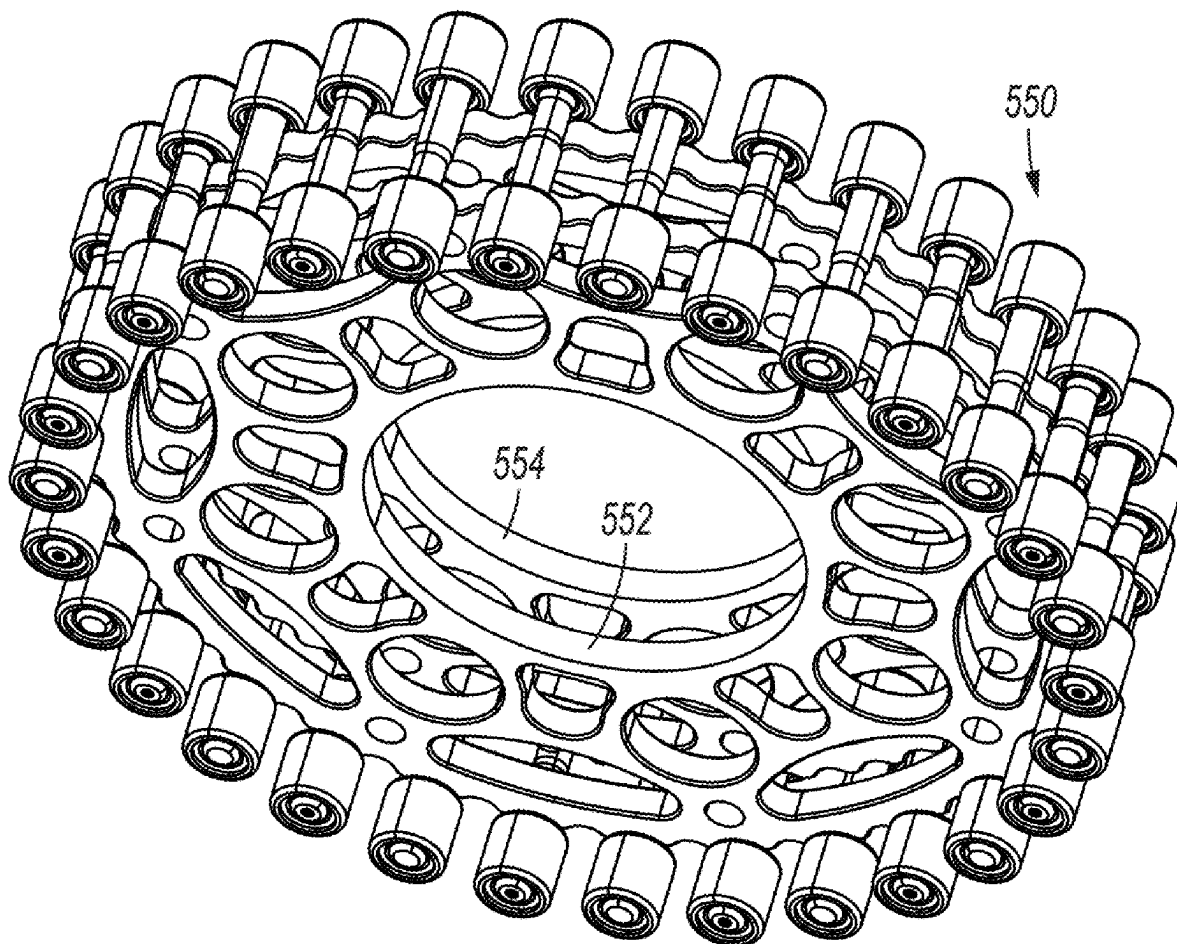




US 20250264148A1

(19) **United States**(12) **Patent Application Publication****Sweeney et al.**(10) **Pub. No.: US 2025/0264148 A1**(43) **Pub. Date: Aug. 21, 2025**(54) **CYCLOID GEAR ASSEMBLY WITH
PARTIAL CONTACT AND RELATED
TECHNOLOGY**(52) **U.S. Cl.**
CPC *F16H 1/32* (2013.01); *F16H 2001/325*
(2013.01)(71) Applicant: **Agility Robotics, Inc.**, Pittsburgh, PA
(US)(72) Inventors: **Kevin Sweeney**, Albany, OR (US);
Jonathan Hurst, Albany, OR (US)(21) Appl. No.: **18/884,700**(22) Filed: **Sep. 13, 2024****Related U.S. Application Data**(60) Provisional application No. 63/554,680, filed on Feb.
16, 2024, provisional application No. 63/569,683,
filed on Mar. 25, 2024, provisional application No.
63/691,950, filed on Sep. 6, 2024.**Publication Classification**(51) **Int. Cl.**
F16H 1/32 (2006.01)(57) **ABSTRACT**

A gear assembly in accordance with at least some embodiments of the present technology includes first and second supports extending circumferentially around an assembly axis in first and second planes, respectively. The gear assembly includes a first transfer member having first lobes and first troughs circumferentially alternating around the assembly axis in a third plane. The gear assembly includes a second transfer member having second lobes and second troughs circumferentially alternating around the assembly axis in a fourth plane. The third and fourth planes are between the first and second planes along the assembly axis. The gear assembly includes first and second pins circumferentially interspersed around the assembly axis and extending between the first and second supports. The gear assembly transfers torque at least primarily via contact between the first pins and the first lobes and via contact between the second pins and the second lobes.



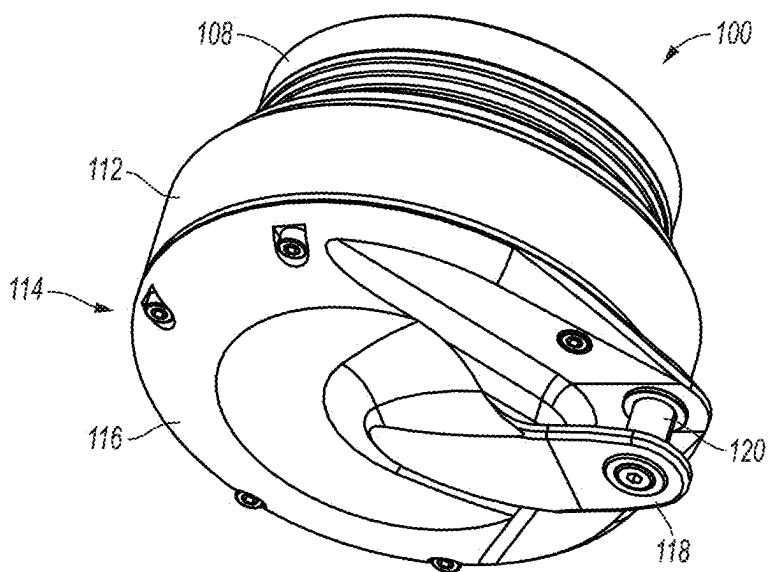


Fig. 1

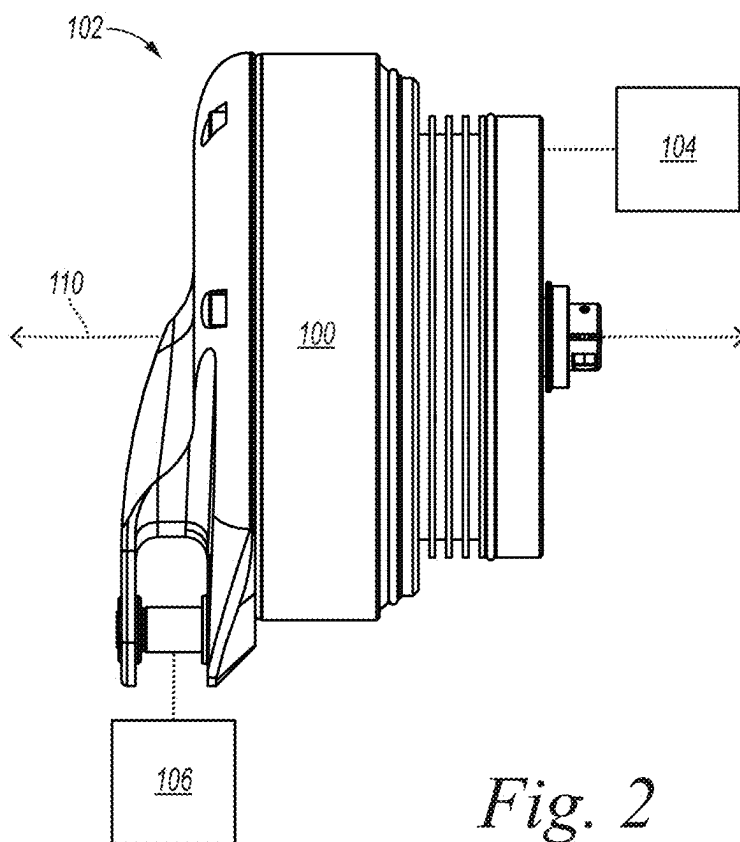


Fig. 2

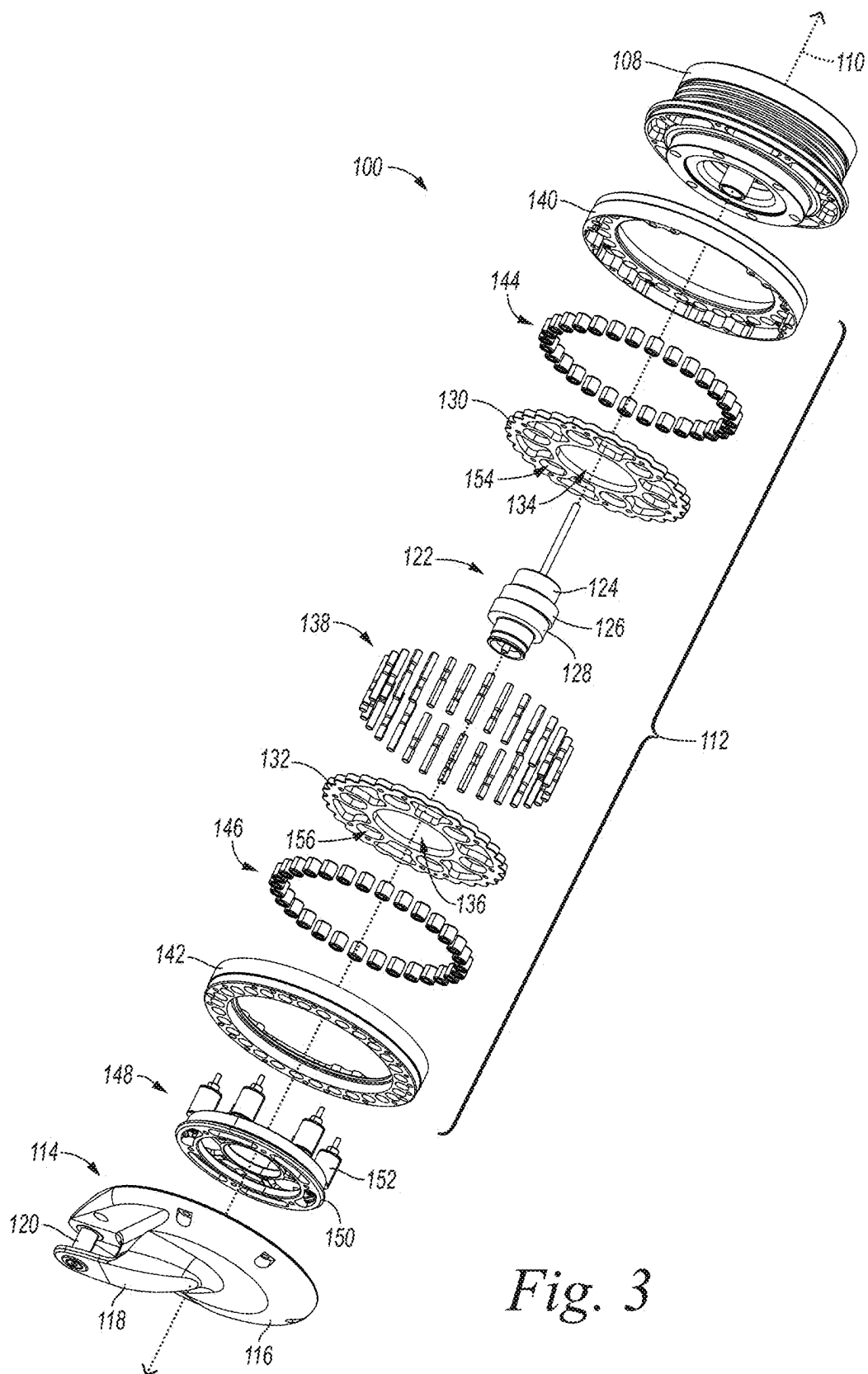


Fig. 3

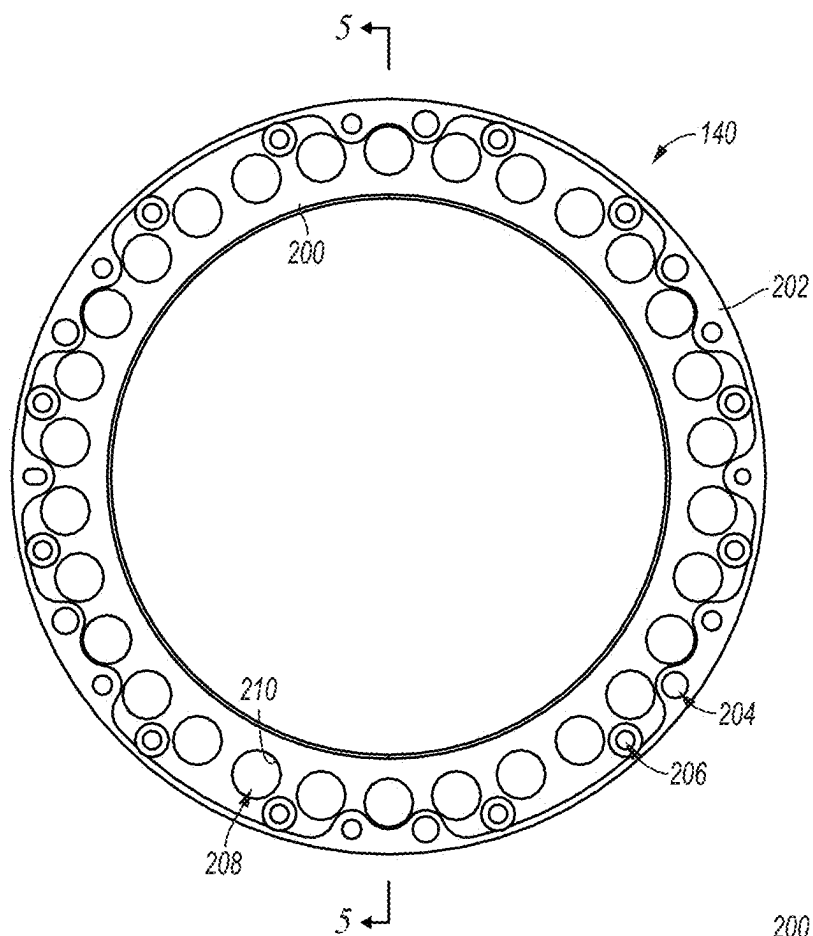


Fig. 4

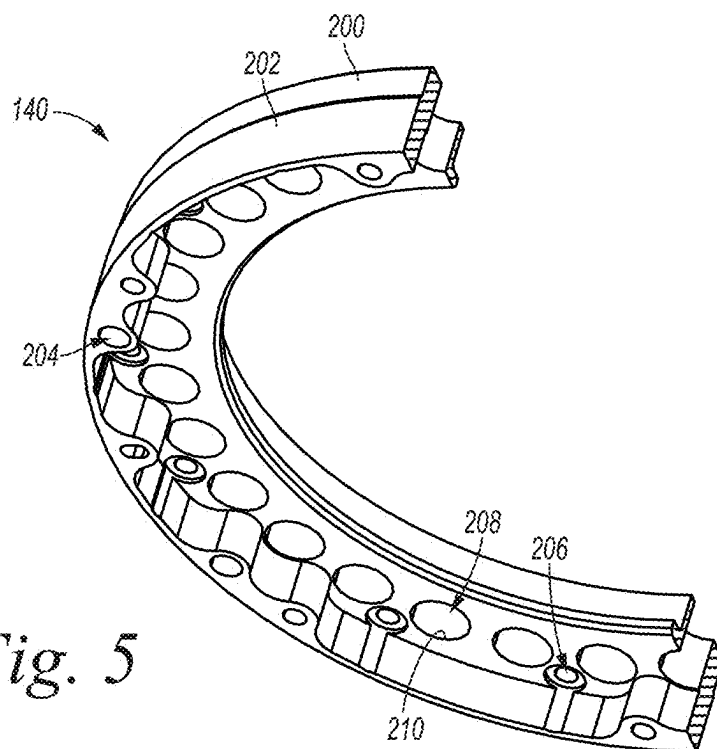


Fig. 5

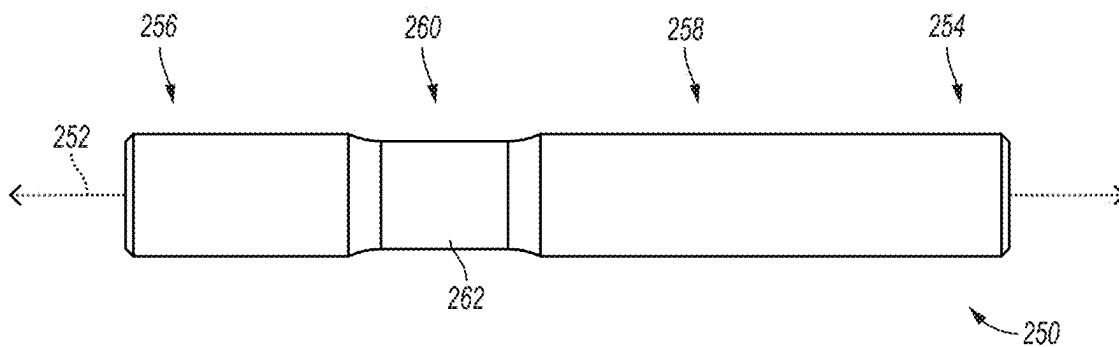


Fig. 6

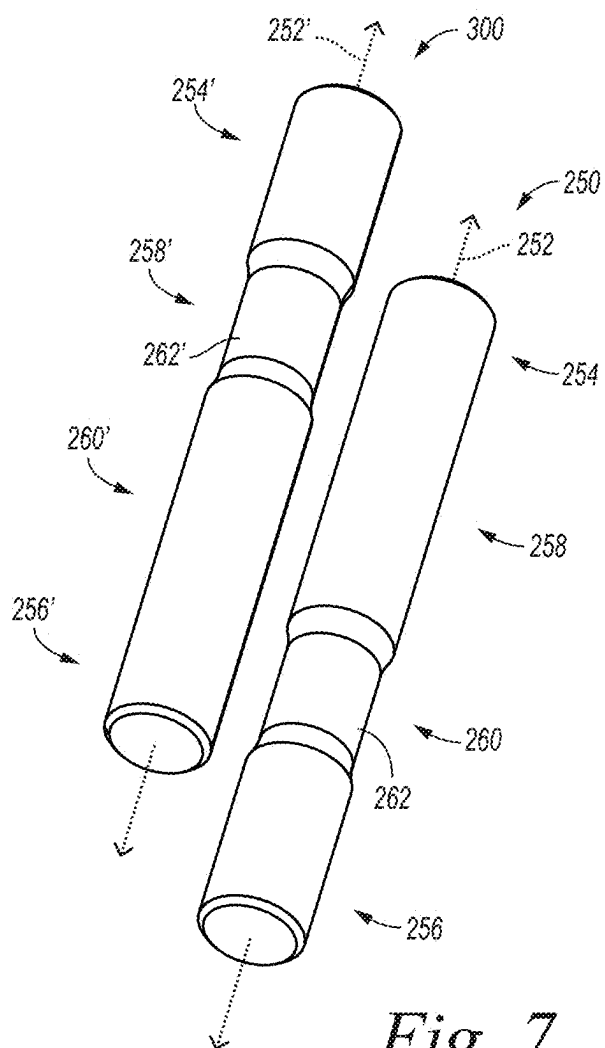


Fig. 7

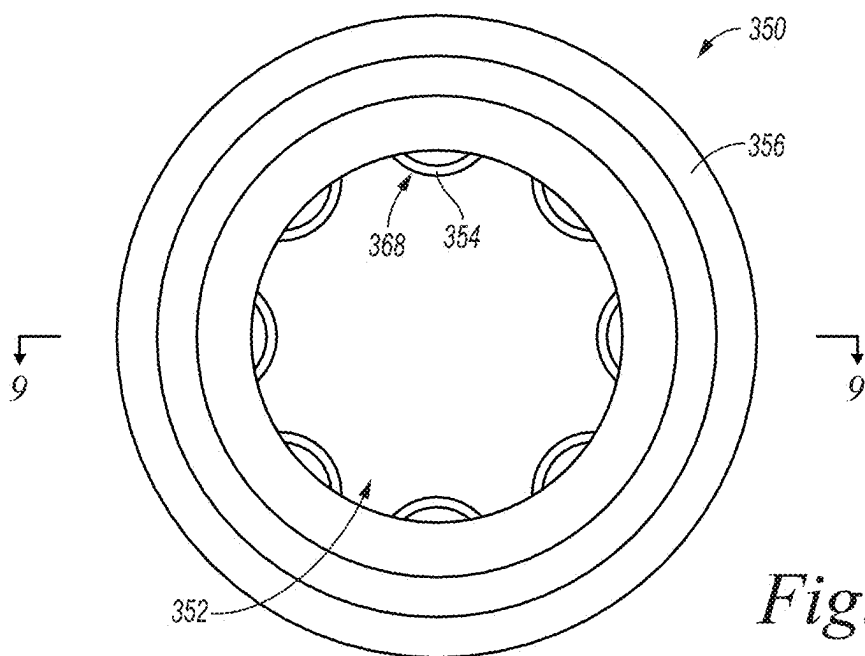


Fig. 8

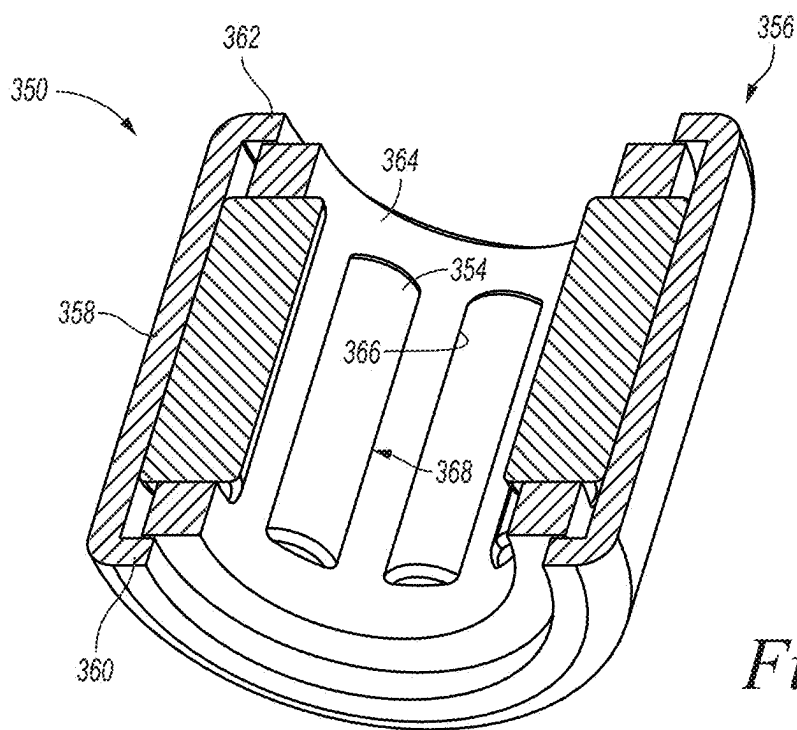


Fig. 9

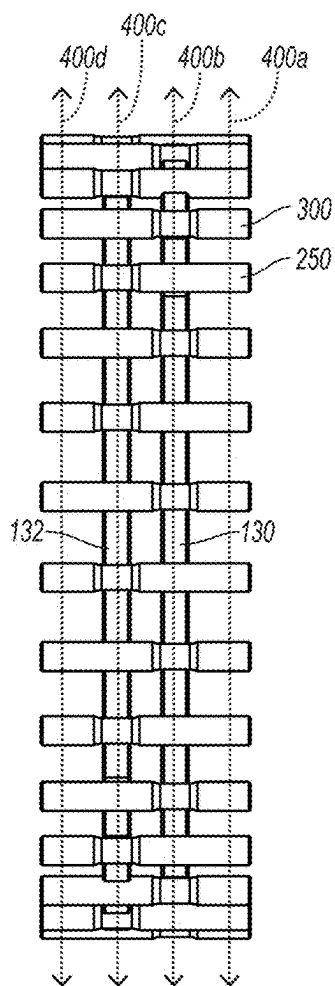


Fig. 10

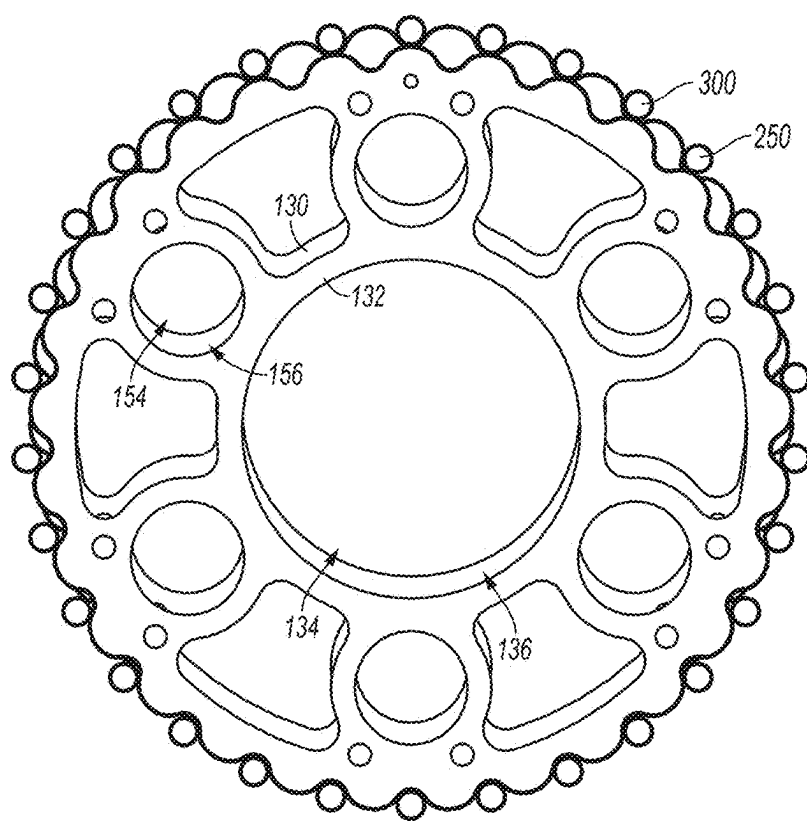


Fig. 11

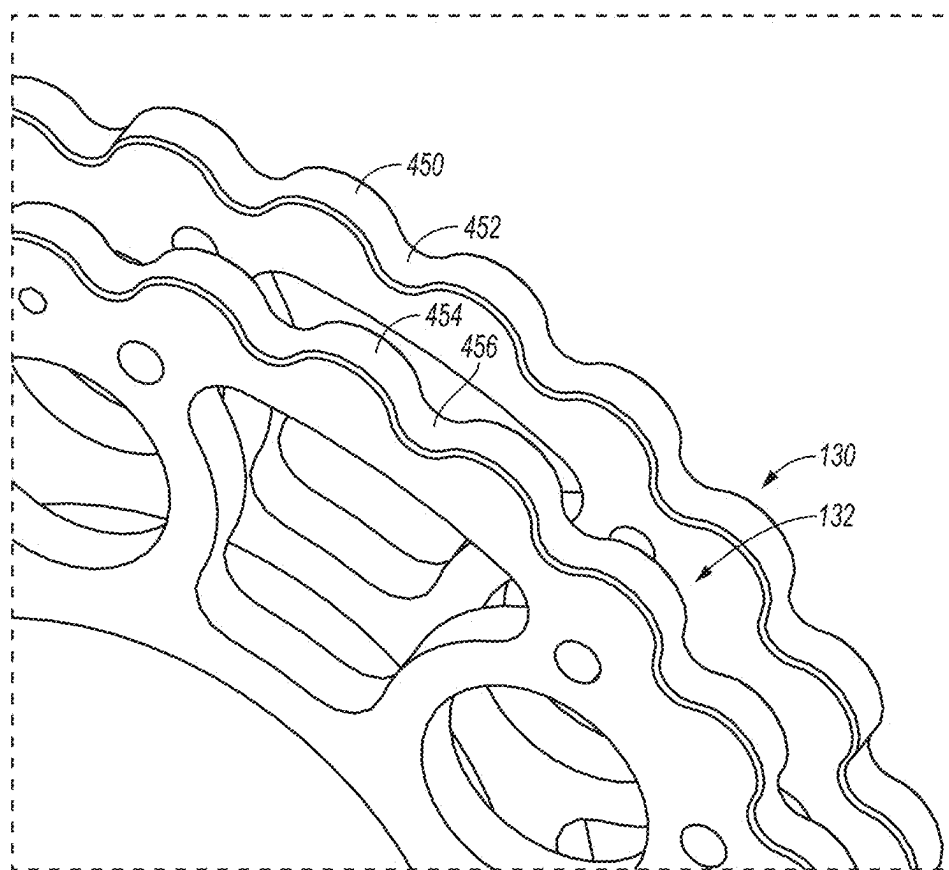
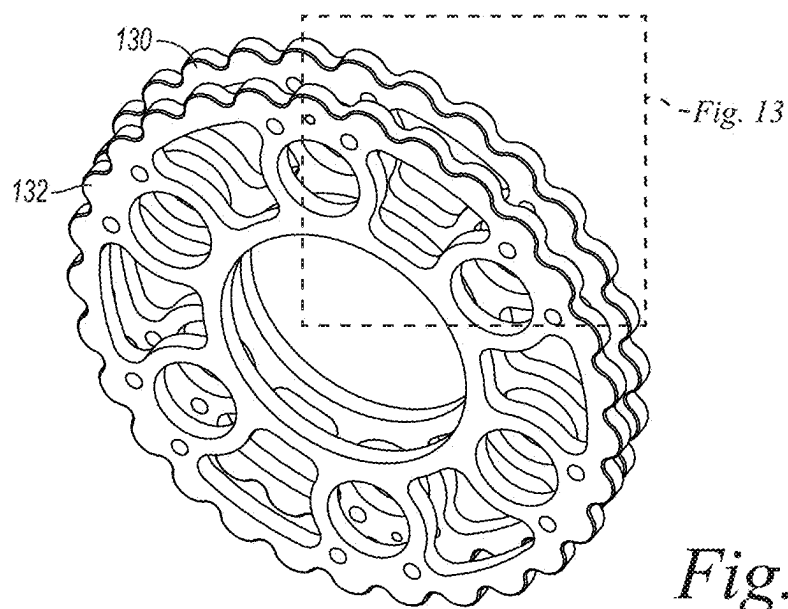


Fig. 13

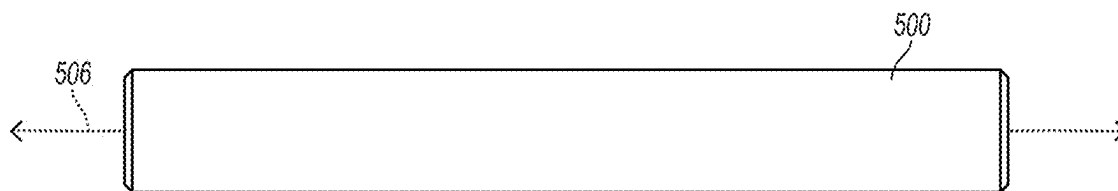


Fig. 14

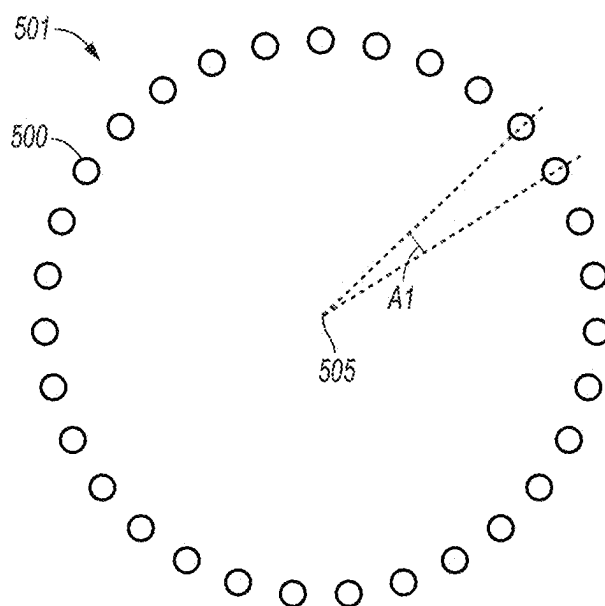


Fig. 15

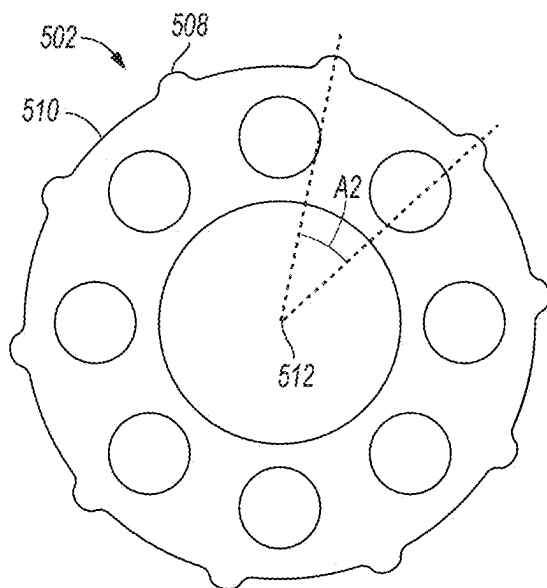


Fig. 16

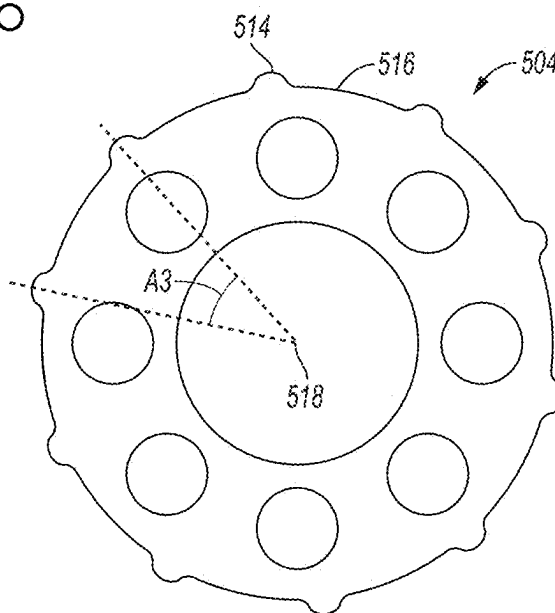


Fig. 17

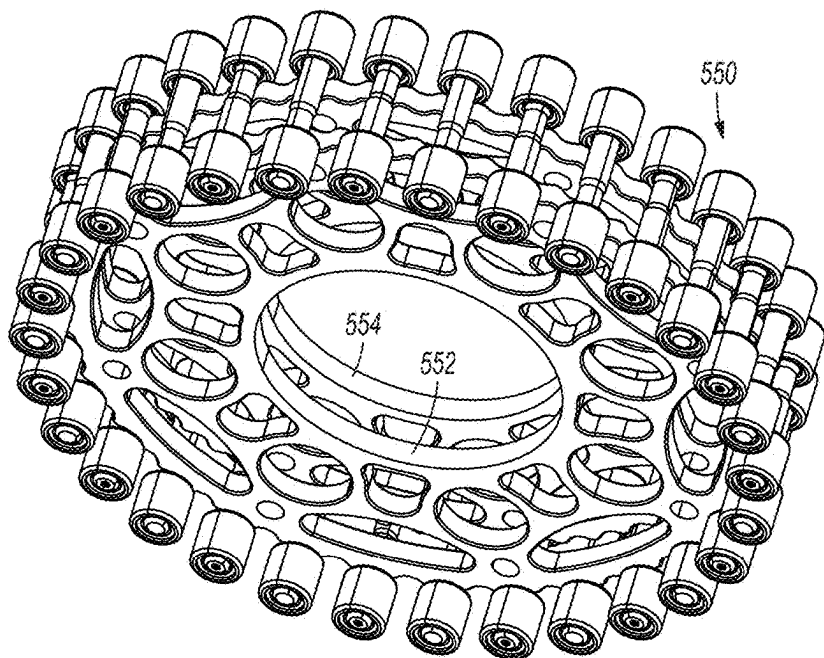


Fig. 18

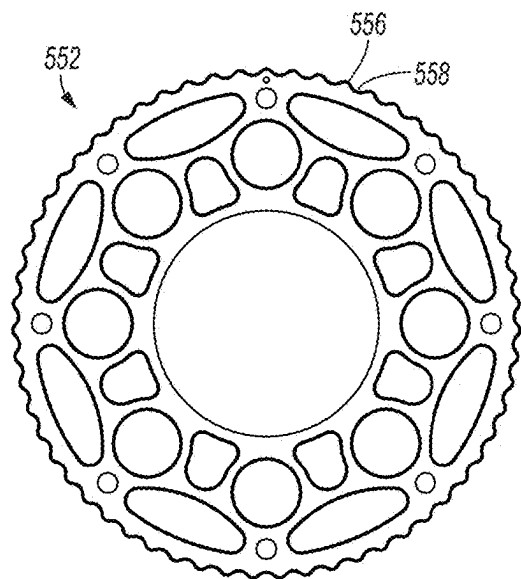


Fig. 19

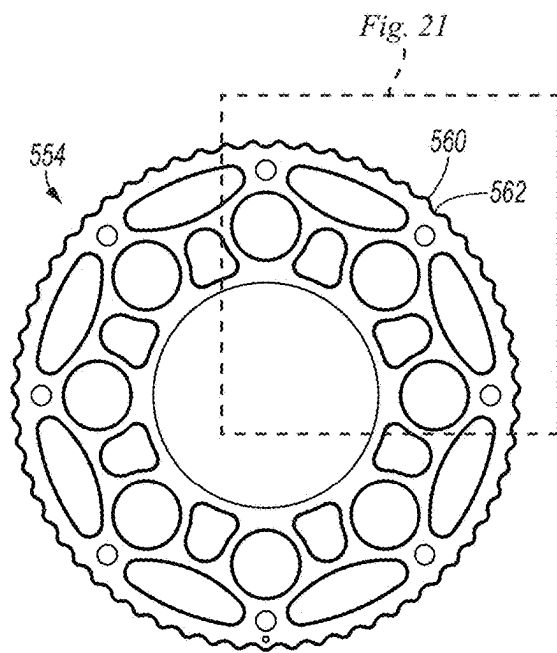


Fig. 20

Fig. 21

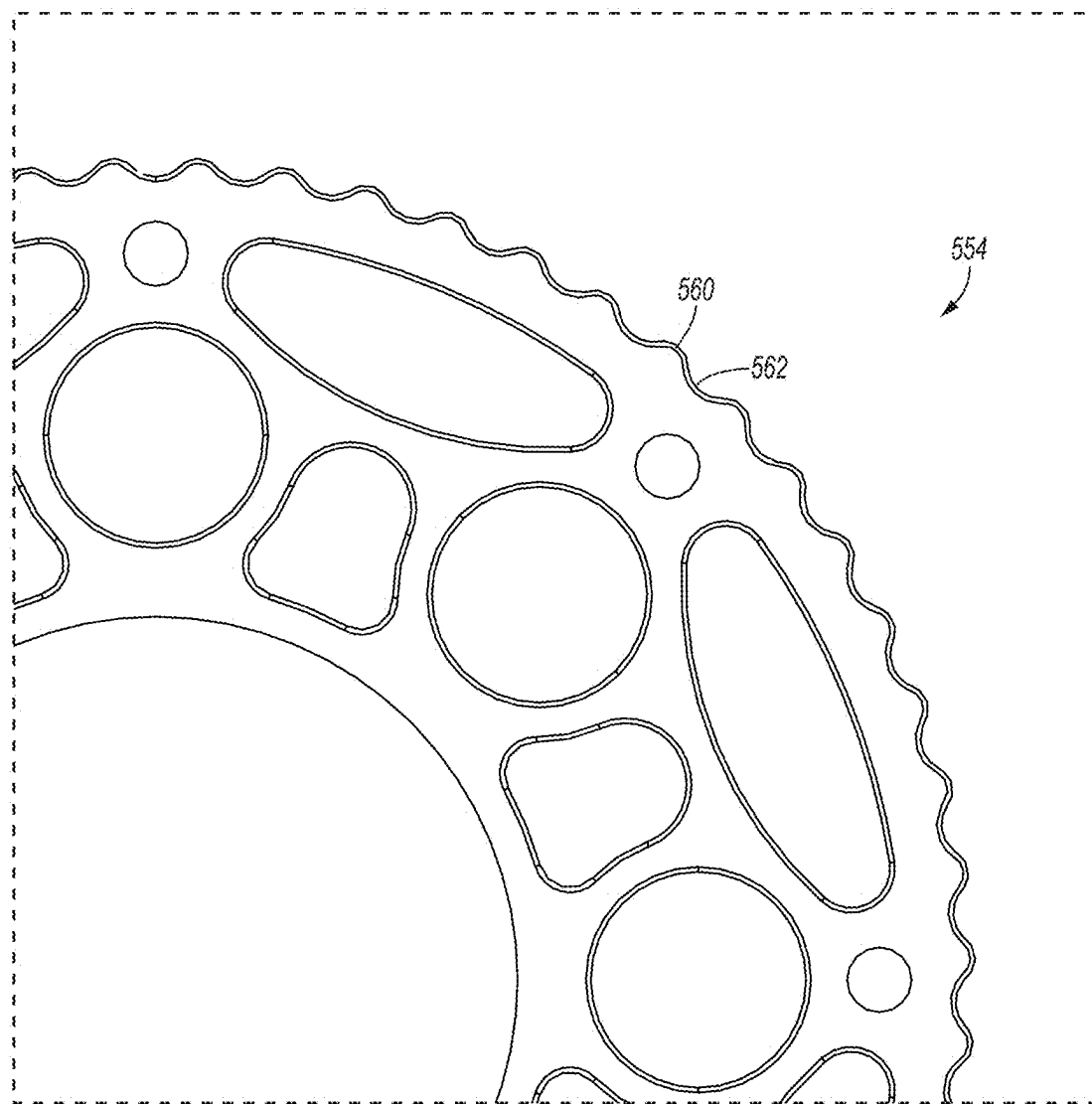


Fig. 21

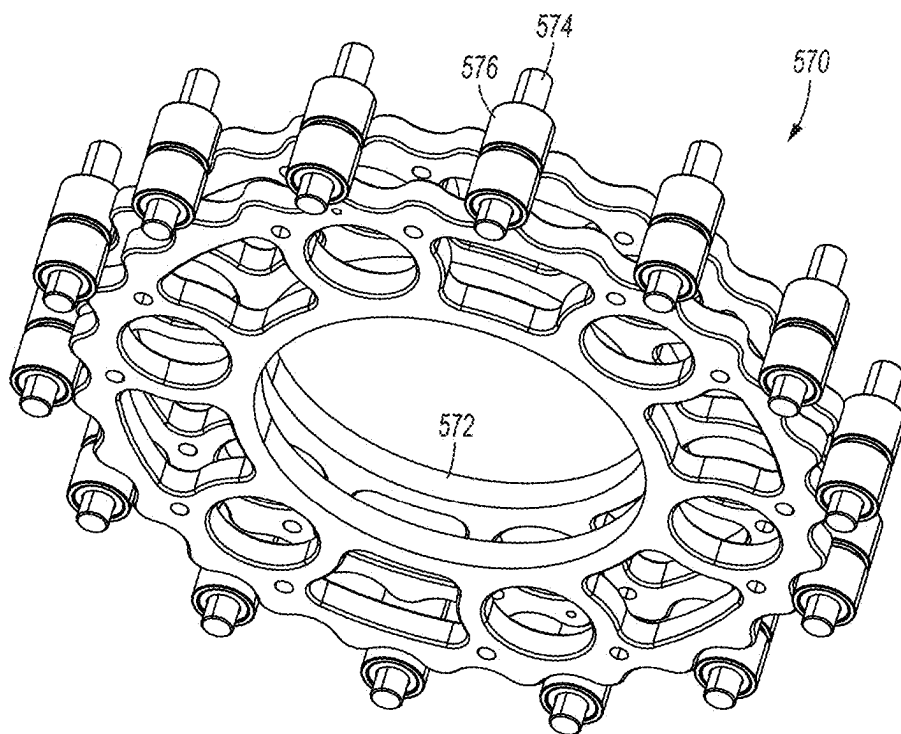


Fig. 22

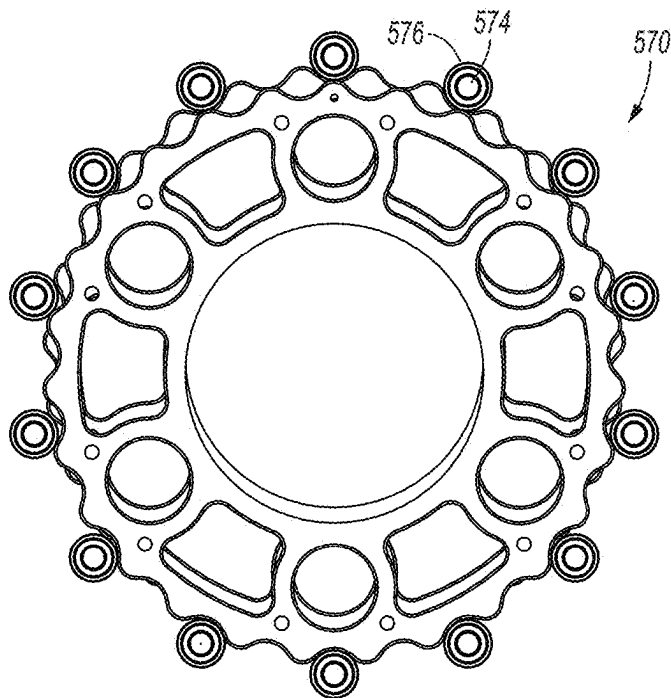


Fig. 23

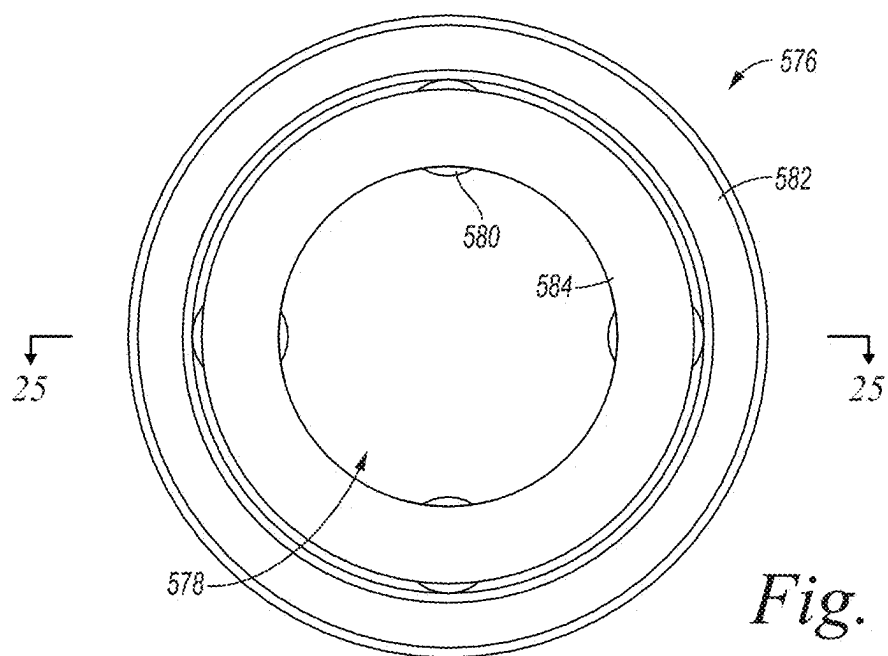


Fig. 24

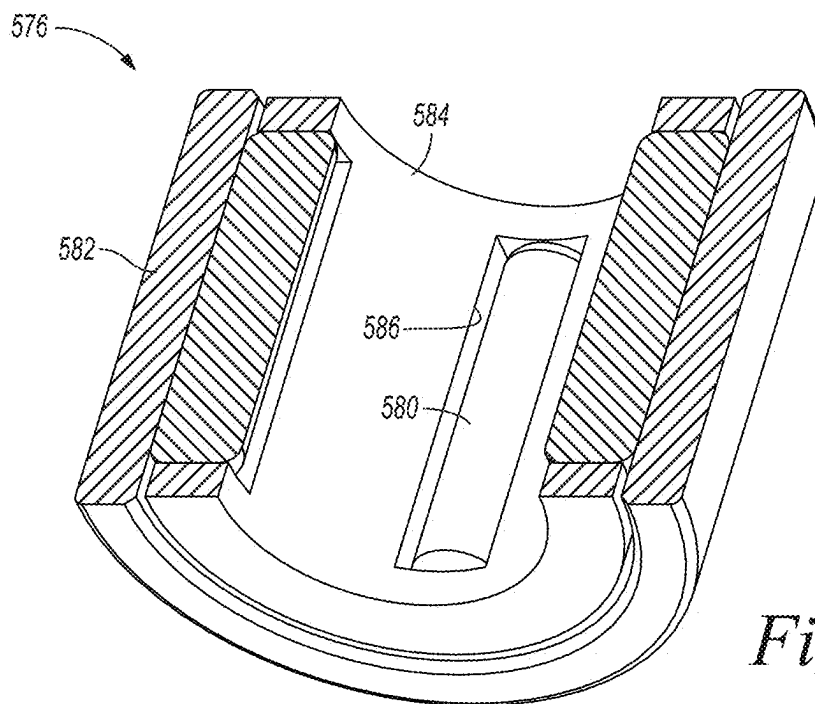


Fig. 25

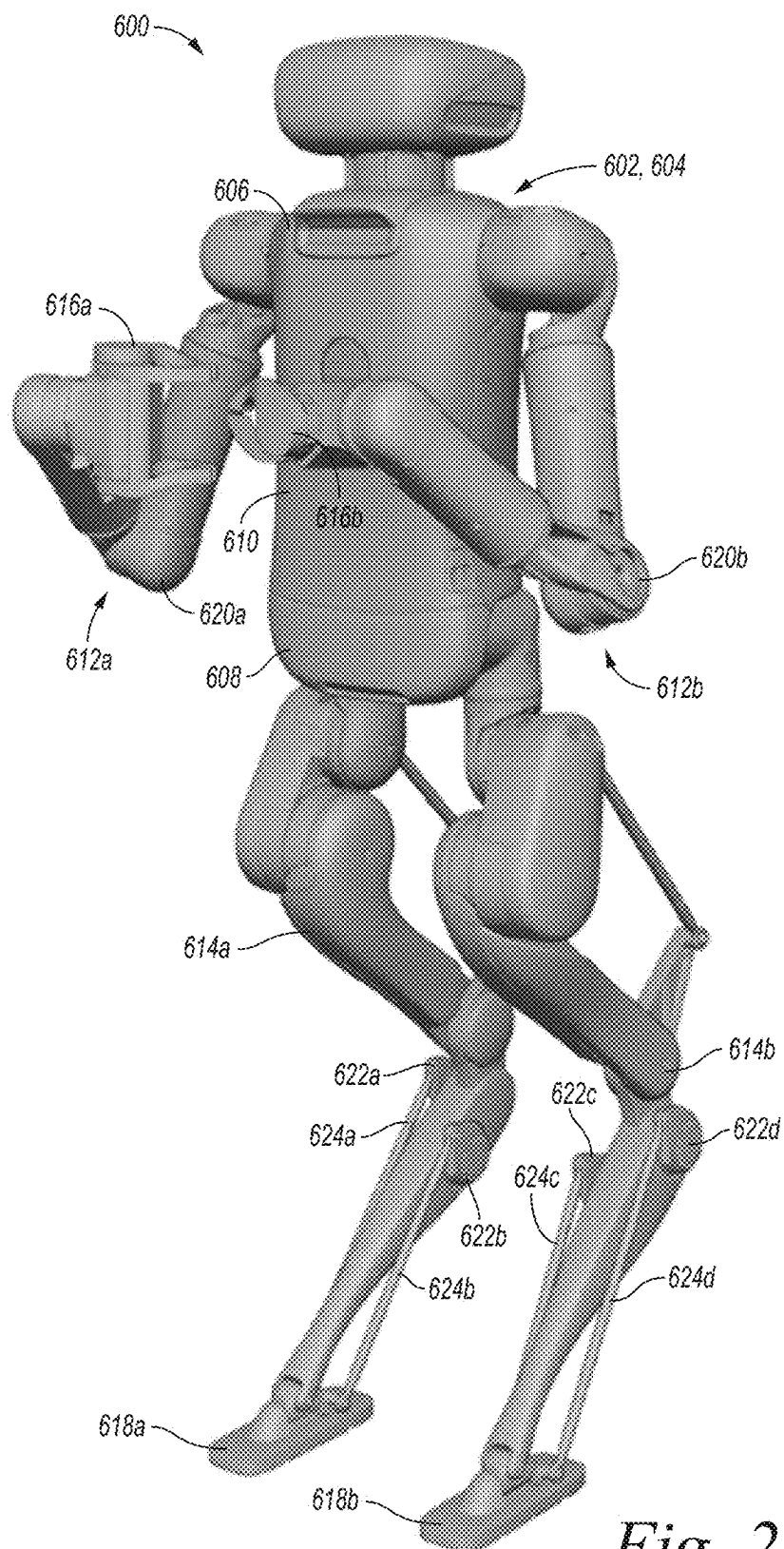


Fig. 26

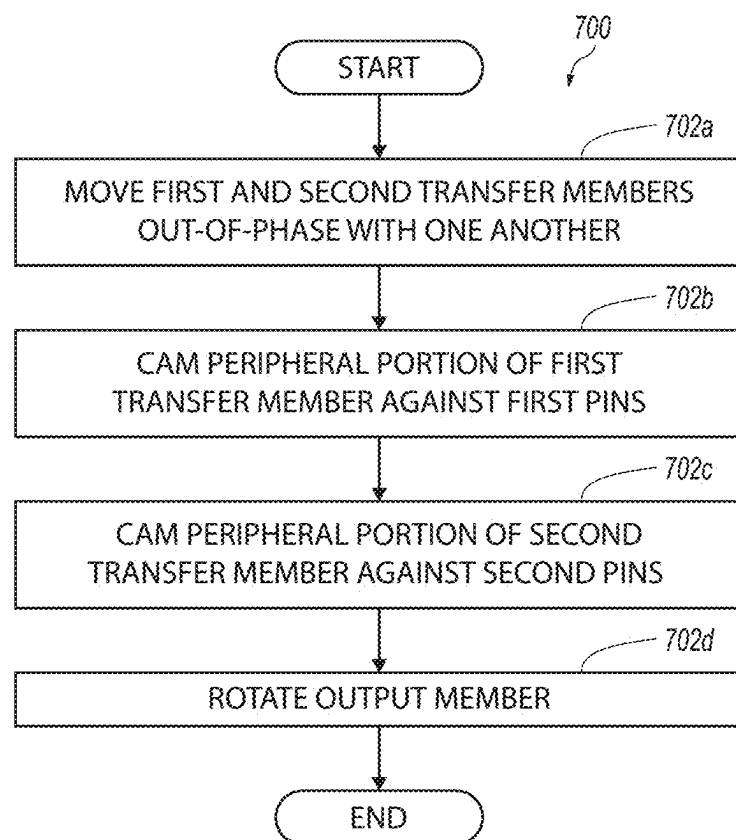


Fig. 27

CYCLOID GEAR ASSEMBLY WITH PARTIAL CONTACT AND RELATED TECHNOLOGY

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This claims the benefit of U.S. Provisional Application No. 63/554,680, filed Feb. 16, 2024, U.S. Provisional Application No. 63/569,683, filed Mar. 25, 2024, and U.S. Provisional Application No. 63/691,950, filed Sep. 6, 2024. Each of the foregoing applications is incorporated herein by reference in its entirety. To the extent the foregoing applications or any other material incorporated by reference conflicts with the present disclosure, the present disclosure controls.

TECHNICAL FIELD

[0002] The present technology relates to cycloid gear assemblies, such as cycloid gear assemblies of robot actuators.

BACKGROUND

[0003] Much of the work that humans currently perform is amenable to automation using robotics. For example, large numbers of human workers currently focus on executing actions that require little or no reasoning, such as predefined relocations of items and containers at order-fulfillment centers. Such actions may occur millions of times a day at a single order-fulfillment center and billions of times a day across a network of order-fulfillment centers. Human effort would be better applied to more complex tasks, particularly those involving creativity, advanced problem solving, and social interaction. Presently, however, the need for order-fulfillment centers is large and rapidly increasing. Some analysts forecast a shortage of a million or more workers to staff order-fulfillment centers within the next ten to fifteen years. Due to the importance of this field, even small improvements in efficiency can have major impacts on macroeconomic productivity. For at least these reasons, there is a significant and growing need for innovation that supports automating tasks that humans currently perform at order-fulfillment centers and elsewhere.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Certain aspects of the present technology can be better understood with reference to the following drawings. The relative dimensions in the drawings may be to scale with respect to some embodiments of the present technology. With respect to other embodiments, the drawings may not be to scale. The drawings may also be enlarged arbitrarily. For clarity, reference-number labels for analogous components or features may be omitted when the appropriate reference-number labels for such analogous components or features are clear in the context of the specification and all of the drawings considered together. Furthermore, the same reference numbers may be used to identify analogous components or features in multiple described embodiments.

[0005] FIG. 1 is a perspective view of an actuator in accordance with at least some embodiments of the present technology.

[0006] FIG. 2 is a partially schematic side profile view of a robot joint assembly including the actuator of FIG. 1 in accordance with at least some embodiments of the present technology.

[0007] FIG. 3 is an exploded perspective view of selected components of the actuator of FIG. 1.

[0008] FIG. 4 is a front profile view of a first support of the actuator of FIG. 1.

[0009] FIG. 5 is a cross-sectional perspective view of the first support of the actuator of FIG. 1 taken along the line 5-5 in FIG. 4.

[0010] FIG. 6 is a side profile view of a first pin of the gear assembly of the actuator of FIG. 1.

[0011] FIG. 7 is a perspective view of the first pin and a circumferentially neighboring second pin of the gear assembly of the actuator of FIG. 1.

[0012] FIG. 8 is a front profile view of a roller bearing of the gear assembly of the actuator of FIG. 1.

[0013] FIG. 9 is a cross-sectional perspective view of the roller bearing of the gear assembly of the actuator of FIG. 1 taken along the line 9-9 in FIG. 8.

[0014] FIGS. 10 and 11 are a side profile view and a front profile view, respectively, of transfer members and pins of the gear assembly of the actuator of FIG. 1.

[0015] FIG. 12 is a perspective view of transfer members of the gear assembly of the actuator of FIG. 1.

[0016] FIG. 13 is an enlargement of a portion of FIG. 12.

[0017] FIGS. 14, 15, 16 and 17 are, respectively, a side profile view of a pin, a side profile view of a pin array, a side profile view of a first transfer member, and a side profile view of a second transfer member of a gear assembly of an actuator in accordance with another embodiment of the present technology.

[0018] FIGS. 18, 19 and 20 are, respectively, a perspective view of transfer members, pins, and roller bearings, a side profile view of a first transfer member, and a side profile view of a second transfer member of a gear assembly of an actuator in accordance with another embodiment of the present technology.

[0019] FIG. 21 is an enlargement of a portion of FIG. 20.

[0020] FIGS. 22 and 23 are, respectively, a perspective view and a side profile view of transfer members, pins, and roller bearings of a gear assembly of an actuator in accordance with another embodiment of the present technology.

[0021] FIG. 24 is a front profile view of a roller bearing of the gear assembly of the actuator of FIGS. 22 and 23.

[0022] FIG. 25 is a cross-sectional perspective view of the roller bearing of the gear assembly of the actuator of FIGS. 22 and 23 taken along the line 25-25 in FIG. 24.

[0023] FIG. 26 is a perspective view of a mobile robot including an actuator in accordance with at least some embodiments of the present technology.

[0024] FIG. 27 is a block diagram corresponding to a method involving an actuator in accordance with at least some embodiments of the present technology.

DETAILED DESCRIPTION

[0025] Robots perform mechanical work via actuators. A typical actuator in an electromechanical robot includes an electrical motor and a gear assembly. The electrical motor uses electricity from a power source to rotate a shaft at a relatively high speed. The gear assembly converts this high-speed rotation into lower-speed rotation more suitable for a controlled mechanical action, such as moving a robot

link via a robot joint. Rolling-contact cycloid and strain-wave are two types of gear assemblies used in advanced robotics. Performance categories that differentiate these types of gear assemblies include torque-to-weight ratio, torque-to-size ratio, reduction ratio, backlash, efficiency, transparency, miniaturizability, and shock resistance. Reduction ratio is the ratio of the number of revolutions per time of the input to the gear assembly divided by the number of revolutions per time of the output from the gear assembly. Backlash is the clearance or play between gears during operation, which, in excess, can cause imprecise and jerky movements. With exceptions, strain-wave gear assemblies tend to perform relatively well with respect to torque-to-weight ratio, torque-to-size ratio, backlash, and miniaturizability. Also with exceptions, rolling-contact cycloid gear assemblies tend to perform relatively well with respect to efficiency, transparency, and shock resistance. Strain-wave gear assemblies have certain advantages at high reduction ratios whereas rolling-contact cycloid gear assemblies have certain advantages at lower reduction ratios. Different applications call for different reduction ratios, so the desirability of compatibility with higher or lower reduction ratios tends to be application specific. Furthermore, the noted performance differentiators are not universal. For example, a high-quality rolling-contact cycloid gear assembly may exhibit lower backlash than a low-quality strain-wave gear assembly.

[0026] With respect to most performance categories, the differences between strain-wave and rolling-contact cycloid gear assemblies are small enough that either one is acceptable for a given application. Indeed, it is typical to accept performance tradeoffs in connection with selecting an actuator type for an application instead of attempting to maximize performance in all categories. Three notable exceptions to this approach, however, are shock resistance, miniaturizability, and transparency. Performance in these categories tends to be determinative. Strain-wave gear assemblies often exhibit unacceptably low shock resistance. Moreover, this feature of strain-wave gear assemblies can be difficult to avoid because operating a strain-wave gear assembly involves deforming a flexspline, which must be flexible enough to accommodate the deformation. Good shock resistance and sufficient deformability tend to be mutually exclusive in practice. Accordingly, rolling-contact cycloid gear assemblies of all sizes tend to significantly outperform counterpart strain-wave gear assemblies in the category of shock resistance.

[0027] Moreover, strain-wave gear assemblies often exhibit relatively poor transparency. Transparency describes how readily output torque from an actuator can be predicted. Actuators operate at different efficiencies depending on load and speed. When these efficiencies fall within a relatively wide range, transparency is low. In contrast, when these efficiencies fall within a relatively narrow range, transparency is high. The latter is beneficial for control and simulation processes, among other things. As with shock resistance, rolling-contact cycloid gear assemblies reliably outperform strain-wave gear assemblies with regard to transparency. For example, the efficiency of a conventional strain-wave gear assembly may fall within a range from 50% to 85%. In contrast, the efficiency of a rolling-contact cycloid gear assembly in accordance with at least some embodiments of the present technology is expected to fall within a range from 89% to 99%.

[0028] Conventional rolling-contact cycloid gear assemblies, however, are prohibitively difficult to miniaturize beyond a certain level. Thus, where size is limited and high shock forces are possible and/or high transparency is necessary, neither conventional strain-wave gear assemblies nor conventional rolling-contact cycloid gear assemblies are suitable. Moreover, there is room for improvement in conventional gear assemblies of all sizes and types, particularly with regard to cost and complexity. Conventional rolling-contact cycloid gear assemblies, for example, tend to have relatively large numbers of high-precision parts, which can make them expensive and difficult to manufacture. For the foregoing and/or other reasons, there is a need for innovation in this field.

[0029] Gear assemblies and related devices, systems, and methods in accordance with embodiments of the present technology at least partially address one or more problems or limitations associated with conventional technologies. A gear assembly in accordance with at least some embodiments of the present technology has generally a rolling-contact cycloidal architecture, but with a partial rather than a full set of circumferential contact areas relative to conventional counterparts. This feature is characterized in at least some instances herein as “partial contact.” Partial contact includes features characterized herein as “sparse contact” and “alternating contact,” among others. These features are described in detail below. Partial contact can have a variety of advantages. For example, it can facilitate direct contact between transfer members (e.g., cycloid disks) and pins without the need for intervening roller bearings. This, in turn, can allow for a higher reduction ratio in a smaller overall actuator size than would otherwise be possible. Relatedly, partial contact can allow roller bearings to be offset from transfer members, which can likewise reduce overall actuator size. In addition or alternatively, partial contact can allow for the use of fewer roller bearings and/or roller bearings of a type (e.g., drawn-cup) of relatively low cost and small size. Still other advantages in addition to or instead of the foregoing are also possible.

[0030] A gear assembly in accordance with a particular embodiment includes pins that bridge an area adjacent to two transfer members and engage the transfer members unequally during operation. This unequal engagement can include contacting one of the transfer members and remaining out of contact with the other. In an example, pins configured to engage a first transfer member and to avoid engaging a second transfer member are circumferentially interspersed with pins configured to engage the second transfer member and to avoid engaging the first transfer member. The unequal engagement can be associated with a difference in the shape of the pins, a difference in the orientation of the pins, a difference in the shape of the transfer members, and/or a difference in the orientation of the transfer members, among other possibilities. Furthermore, as mentioned above, the pins can extend between roller bearings of a type well suited to miniaturization and low-cost production. For example, the pins can extend between drawn-cup needle roller bearings at circumferentially distributed sockets of axially spaced apart supports. Gear assemblies in accordance with at least some embodiments of the present technology are expected to exhibit advantageous characteristics, such as a previously unavailable combination of high miniaturizability, high shock resistance, and high reduction ratio.

[0031] The foregoing and other features of devices, systems, and methods in accordance with various embodiments of the present technology are further described below with reference to FIGS. 1-27. Although methods, devices, and systems may be described herein primarily or entirely in the context of actuators of mobile robots, other contexts are within the scope of the present technology. For example, suitable features of described methods, devices, and systems can be implemented in the context of stationary robots or in non-robot contexts that call for actuators with cycloid-type gearing, such as certain vehicles, pumps, winches, etc. Furthermore, it should be understood, in general, that other methods, devices, and systems in addition to those disclosed herein are within the scope of the present technology. For example, methods, devices, and systems in accordance with embodiments of the present technology can have different and/or additional configurations, components, procedures, etc. than those disclosed herein. Moreover, methods, devices, and systems in accordance with embodiments of the present technology can be without one or more of the configurations, components, procedures, etc. disclosed herein without deviating from the present technology.

Examples of Actuators

[0032] FIG. 1 is a perspective view of an actuator 100 in accordance with at least some embodiments of the present technology. FIG. 2 is a partially schematic side profile view of a robot joint assembly 102 including the actuator 100 in accordance with at least some embodiments of the present technology. With reference to FIGS. 1 and 2 together, the robot joint assembly 102 can include a link 104 and rod 106 (both shown schematically) connected to one another via the actuator 100. In the illustrated embodiment, the actuator 100 is configured to move the rod 106 relative to the link 104. In another embodiment, as discussed below, a counterpart of the actuator 100 can be configured to cause an opposite relative motion. With reference again to FIGS. 1 and 2, the actuator 100 can include a motor 108 configured to convert electricity into torque. In at least some cases, the motor 108 is configured to rotate a shaft (not shown in FIGS. 1 and 2) about an assembly axis 110. The actuator 100 can further include a gear assembly 112 through which the rod 106 is connected to the motor 108. The gear assembly 112 can include a crank 114 including a plate 116 shaped as a disk in a plane perpendicular to the assembly axis 110. The crank 114 can further include a yoke 118 carried by the plate 116 and a pivot 120 carried by the yoke 118. The pivot 120 can be cylindrical, have a laterally offset position relative to the assembly axis 110, and have a length parallel to the assembly axis 110. The rod 106 can be configured to rotate relative to the crank 114 via the pivot 120 as the actuator 100 moves the crank 114 relative to the link 104. Thus, the crank 114 can be an output member of the gear assembly 112. Other output members are also possible. For example, a counterpart of the actuator 100 can include an output shaft or another link in place of the crank 114.

[0033] With reference again to the illustrated embodiment, FIG. 3 is an exploded perspective view of selected components of the actuator 100. As shown in FIG. 3, the gear assembly 112 can include cycloid-type internal structures. The gear assembly 112 can include an input assembly 122 kinematically downstream from the motor 108. As parts of the input assembly 122, the gear assembly 112 can include an input shaft 124 configured to rotate about the assembly

axis 110, a first eccentric bearing 126 carried by the input shaft 124, and a second eccentric bearing 128 also carried by the input shaft 124. The first and second eccentric bearings 126, 128 can be connected to the input shaft 124 at different respective positions along the assembly axis 110. Furthermore, the first and second eccentric bearings 126, 128 can protrude radially from the input shaft 124 in circumferentially opposite respective directions relative to the assembly axis 110. In at least some cases, the first and second eccentric bearings 126, 128 are not rotatable relative to the input shaft 124 about the assembly axis 110. For example, the input shaft 124 and the first and second eccentric bearings 126, 128 can include complementary locking features (not shown), such as key and slot features, non-cylindrical interface features, etc. Thus, as the input shaft 124 rotates about the assembly axis 110, protruding portions of the first and second eccentric bearings 126, 128 rotate out-of-phase with one another. The respective rotation of these protruding portions of the first and second eccentric bearings 126, 128 can be radially symmetrical about the assembly axis 110. This can reduce or prevent vibration during operation of the actuator 100, provide internal load balancing, and/or have other advantages.

[0034] The actuator 100 can further include a first transfer member 130 at a position along the assembly axis 110 corresponding to a position of the first eccentric bearing 126 along the assembly axis 110. The actuator 100 can also include a second transfer member 132 at a position along the assembly axis 110 corresponding to a position of the second eccentric bearing 128 along the assembly axis 110. The first transfer member 130 can define a first central opening 134 at which the first eccentric bearing 126 is rotatably disposed. The second transfer member 132 can define a second central opening 136 at which the second eccentric bearing 128 is rotatably disposed. Rotating the first and second eccentric bearings 126, 128 within the first and second central openings 134, 136, respectively, via the input shaft 124 can induce an eccentric wobble in the first and second transfer members 130, 132. This can include urging the first and second transfer members 130, 132 radially outward from the assembly axis 110 in concert with the out-of-phase rotation of the protruding portions of the first and second eccentric bearings 126, 128. Thus, at any given time, a peripheral portion of the first transfer member 130 farthest from the assembly axis 110 can be circumferentially opposite to a peripheral portion of the second transfer member 132 farthest from the assembly axis 110. This relationship can persist as the first and second transfer members also rotate about the assembly axis 110 in response to interaction with other components of the gear assembly 112, as discussed below. In some cases, the actuator 100 includes annular roller bearings (not shown) at interfaces between the first and second eccentric bearings 126, 128 and the first and second transfer members 130, 132, respectively. In other cases, outer surfaces of the first and second eccentric bearings 126, 128 slidably contact inner surfaces of the first and second transfer members 130, 132 respectively.

[0035] With reference again to FIG. 3, the gear assembly 112 can further include structures that interact directly or indirectly with the first and second transfer members 130, 132 to transfer torque. Among these structures, the gear assembly 112 can include a pin array 138, a first support 140, and a second support 142. Individual pins (not labeled in FIG. 3) of the pin array 138 can be elongate and can extend

between the first and second supports **140**, **142**. A distribution of the pins within the pin array **138** can be radially symmetrical about the assembly axis **110**. The number of pins along with the peripheral shapes of the first and second transfer members **130**, **132** can correspond to a reduction ratio of the actuator **100**. In at least some cases, the actuator **100** has an input-to-output reduction ratio within a range from 20:1 to 40:1, such as from 25:1 to 35:1. As discussed in detail below, there may be less load sharing among the pins in the gear assembly **112** and among the pins of other gear assemblies in accordance with at least some embodiments of the present technology than would occur in a conventional gear assembly. Although not necessary for realizing advantages of various embodiments of the present technology, a relatively high number of pins in the pin array **138** (e.g., at least 15 or at least 20) and a corresponding relatively high input-to-output reduction ratio (e.g., at least 15:1 or at least 20:1) can be advantageous to reduce or eliminate any difference in performance associated with this lesser load sharing.

[0036] In some embodiments, individual pins of the pin array **138** are configured to rotate relative to the first and second supports **140**, **142**. To facilitate this rotation, the gear assembly **112** can include a first roller bearing array **144** and a second roller bearing array **146** at the first and second supports **140**, **142**, respectively. In another embodiment, a counterpart of the gear assembly **112** can include stationary pins configured to slidably contact the first and second transfer members **130**, **132**. In general, however, the rotatability of the pins of the pin array **138** in the illustrated embodiment is expected to significantly increase the efficiency of the actuator **100**. Furthermore, in still other embodiments, all pins can contact both transfer members. In these and other cases, contact between the pins and transfer members can be via roller bearings rather than direct. This can reduce or eliminate antagonistic forces from the respective transfer members acting on the pins. As described below, partial contact can still be present in these cases, such as based on a ratio of the total number of pins to the total number of contact features (e.g., lobes) of the corresponding transfer members.

[0037] With reference again to the illustrated embodiment, the gear assembly **112** can include a carrier **148** having a base **150** and rods **152** (one labeled) individually extending from the base **150**. The individual rods **152** can be cylindrical rollers with respective long axes (not shown) parallel to the assembly axis **110**. Furthermore, the rods **152** can be circumferentially distributed around the assembly axis **110**. In at least some cases, the first transfer member **130** defines first peripheral openings **154** (one labeled) also distributed circumferentially around the assembly axis **110** and outwardly positioned relative to the first central opening **134**. Similarly, the second transfer member **132** can define second peripheral openings **154** (one labeled) distributed circumferentially around the assembly axis **110** and outwardly positioned relative to the second central opening **136**. The individual rods **152** can extend through different respective pairs of one of the first peripheral openings **154** and one of the second peripheral openings **156**. The crank **114** can be fixedly connected to the rods **152** via the base **150** such that force exerted against the rods **152** via rotation of the first and second transfer members **130**, **132** about the assembly axis **110** causes rotation of the crank **114** about the assembly axis **110**.

[0038] In some cases, the gear assembly **112** is configured to rotate the crank **114** or another output member relative to the link **104** or another mount fixedly connected to the first and second supports **140**, **142**. With regard to the carrier **148**, this rotation can be in response to force exerted by the first and second transfer members **130**, **132** against the base **150** via the rods **152**. In other cases, output can be in the opposite direction. For example, a counterpart of the gear assembly **112** can include a mount (instead of the crank **114**) fixedly connected to the base **150**. This counterpart of the gear assembly **112** can be configured to rotate the first and second supports **140**, **142** relative to the mount in response to force exerted by the first and second transfer members **130**, **132** against the first and second supports **140**, **142** via the pin array **138**. In still other cases, a counterpart of the gear assembly **112** can be in a kinematic chain in which it causes a kinematically upstream component and a kinematically downstream component to rotate relative to one another simultaneously. Still other operational configurations are also possible.

[0039] With reference again to the illustrated embodiment, FIG. 4 is a front profile view of the first support **140**. FIG. 5 is a cross-sectional perspective view of the first support **140** taken along the line 5-5 in FIG. 4. With reference to FIGS. 1-5 together, the first and second supports **140**, **142** can be configured to be connected to one another around an annular area at peripheral portions of the first and second transfer members **130**, **132**. The first support **140** can include a plate **200** extending around the assembly axis **110** and a collar **202** at an outer periphery of the plate **200** and extending from the plate **200** toward the second support **142** in a direction parallel to the assembly axis **110**. The plate **200** and the collar **202** can be formed together as a single part (as shown) or formed separately and then connected. The first support **140** can define first fastener holes **204** (one labeled) extending through the plate **200** and the collar **202** in a direction parallel to the assembly axis **110**. The gear assembly **112** can include fasteners (e.g., threaded fasteners, pins, etc.) extending through the first fastener holes **204** that secure the first and second supports **140**, **142** to one another. In at least some cases, these fasteners individually extend between and are in contact with the first and second supports **140**, **142**. The first support **140** can further define second fastener holes **206** (one labeled) extending through the plate **200**. The gear assembly **112** can include fasteners (e.g., threaded fasteners, pins, etc.) extending through the second fastener holes **206** that secure the first support **140** to the motor **108**.

[0040] The plate **200** can further define through holes **208** (one labeled) circumferentially distributed around the assembly axis **110**. The first support **140** can include sockets **210** (one labeled) at the through holes **208**. The sockets **210** can also be circumferentially distributed around the assembly axis **110**. In some cases, the sockets **210** encompass the entire through holes **208**. In other cases, the sockets **210** encompass portions of the through holes **208**. Furthermore, counterparts in another embodiment of the present technology can be blind holes. With reference again to the illustrated embodiment, the second support **142** can have features similar to or the same as those of the first support **140**. Features of the second support **142** may be referenced herein with reference numbers matching the reference numbers of corresponding features of the first support **140**, but with an appended prime symbol. In another embodiment, a coun-

terpart of the second support 142 can have different features. In addition or alternatively, counterparts of the first and second supports 140, 142 can be different portions of a unitary structure rather than separate structures.

[0041] FIG. 6 is a side profile view of a first pin 250 of the gear assembly 112. As shown in FIG. 6, the first pin 250 can be elongate and can define a pin axis 252. The first pin 250 can include a first end portion 254 and a second end portion 256 opposite to one another along the pin axis 252. The first pin 250 can further include a first intermediate portion 258 between the first and second end portions 254, 256 and a second intermediate portion 260 between the first intermediate portion 258 and the second end portion 256. The first pin 250 can be configured to contact the first transfer member 130 via the first intermediate portion 258 during operation of the gear assembly 112 as the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. In contrast, the first pin 250 can be configured to remain out of contact with the second transfer member 132 during operation of the gear assembly 112 as the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. Relatedly, the first pin 250 can have a non-uniform transverse cross-sectional area along the pin axis 252. In particular, the first pin 250 can include an annular recess 262 at the second intermediate portion 260. In the gear assembly 112, the first end portion 254 of the first pin 250 can be at the first support 140, the second end portion 256 of the first pin 250 can be at the second support 142, the first intermediate portion 258 of the first pin 250 can contact the first transfer member 130, and the second intermediate portion 260 of the first pin 250 can remain out of contact with the second transfer member 132 via the annular recess 262. As discussed in detail below, the alternating contact relationship between the first and second pins 250, 300 and the first and second transfer members 130, 132 can facilitate miniaturization of the actuator 100 and/or have other advantages.

[0042] FIG. 7 is a perspective view of the first pin 250 and a second pin 300 of the gear assembly 112 that circumferentially neighbors the first pin 250 within the pin array 138. Features of the second pin 300 are labeled in FIG. 7 and may be referenced herein with reference numbers matching the reference numbers of corresponding features of the first pin 250, but with an appended prime symbol. As shown in FIG. 7, the second pin 300 can be the same or similar to the first pin 250, but with the annular recess 262' at the first intermediate portion 258' rather than at the second intermediate portion 260'. Thus, in the gear assembly 112, the first end portion 254' of the second pin 300 can be at the first support 140, the second end portion 256' of the second pin 300 can be at the second support 142, the first intermediate portion 258' of the first pin 250 can remain out of contact with the first transfer member 130 via the annular recess 262', and the second intermediate portion 260' of the second pin 300 can contact the second transfer member 132. Within the pin array 138, the illustrated first pin 250 and other first pins 250 with the same features and orientation relative to the assembly axis 110 as the illustrated first pin 250 can be circumferentially interspersed around the assembly axis 110 with the illustrated second pin 300 and other second pins 300 with the same features and orientation relative to the assembly axis 110 as the illustrated second pin 300. Distributions of

the first and second pins 250, 300 around the assembly axis 110 can be radially symmetrical.

[0043] FIG. 8 is a front profile view of a roller bearing 350 of the gear assembly 112. FIG. 9 is a cross-sectional perspective view of the roller bearing 350 taken along the line 9-9 in FIG. 8. With reference to FIGS. 1-9 together, the individual first pins 250 can be configured to rotate relative to the first and second supports 140, 142 in response to force (e.g., camming) from the first transfer member 130 (e.g., via a peripheral portion of the first transfer member 130) during operation of the gear assembly 112 as the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. Similarly, the individual second pins 300 can be configured to rotate relative to the first and second supports 140, 142 in response to force (e.g., camming) from the second transfer member 132 (e.g., via a peripheral portion of the second transfer member 132) during operation of the gear assembly 112 as the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. The roller bearing 350 and other roller bearings 350 within the first and second roller bearing arrays 144, 146 can reduce friction during operation of the gear assembly 112 and thereby increase the efficiency of the actuator 100. Locating the roller bearings 350 at interfaces between the first and second pins 250, 300 and the first and second supports 140, 142 rather than at interfaces between the first and second pins 250, 300 and the first and second transfer members 130, 132 can facilitate miniaturization of the actuator 100 and/or have other advantages.

[0044] As shown in FIGS. 8 and 9, the roller bearing 350 can define a cylindrical cavity 352 having a diameter corresponding to a diameter of the first and second end portions 254, 256, 254', 256' of the first and second pins 250, 300. The roller bearing 350 can include rollers 354 (one labeled) aligned with and circumferentially distributed around the cylindrical cavity 352. The roller bearing 350 can further include an annular frame 356 carrying the rollers 354. The annular frame 356 can include a cylindrical casing 358 extending around the rollers 354, a first lip 360 extending inwardly from the cylindrical casing 358 at one end of the cylindrical cavity 352 and a second lip 362 extending inwardly from the cylindrical casing 358 at an opposite end of the cylindrical cavity 352. The roller bearing 350 can further include a spacer 364 defining slots 366 in which the rollers 354 are respectively disposed. The individual rollers 354 can define a cylindrical outer surface 368 partially covered by the spacer 364 and the cylindrical casing 358 and partially exposed at the cylindrical cavity 352. The cylindrical casing 358 can be configured to resist hertzian contact stress, but not operating loads. Accordingly, the cylindrical casing 358 can be relatively thin and lightweight. The roller bearing 350 can be configured to resist deformation from operating loads at least primarily via encasement in an external structure.

[0045] In at least some cases, the roller bearing 350 is a drawn-cup needle roller bearing. Furthermore, the first and second pins 250, 300 can contact the cylindrical outer surfaces 368 of the rollers 354 directly. Due to these and/or other features, the roller bearings 350 can be well suited to miniaturization. In contrast to other types of roller bearings (e.g., machined-ring needle roller bearings), it can be advantageous for drawn-cup needle roller bearings to be supported externally to reduce or prevent deformation in response to

high loads. In the illustrated embodiment, the roller bearings 350 are at the first and second supports 140, 142. For example, the individual roller bearings 350 can be at least partially disposed within the individual sockets 210. In the gear assembly 112, the first and second pins 250, 300 can individually extend between different respective pairs of one of the roller bearings 350 at the first support 140 and one of the roller bearings 350 at the second support 142.

[0046] FIGS. 10 and 11 are a side profile view and a front profile view, respectively, of the first and second transfer members 130, 132 and all of the first and second pins 250, 300 of the gear assembly 112 at a given time during operation of the gear assembly 112. FIG. 10 also shows four planes 400a-400d related to the relative positions of various portions of the gear assembly 112. With reference to FIGS. 1-11 together, the planes 400a-400d can intersect the assembly axis 110 and be spaced apart from one another along the assembly axis 110 at successively farther positions from the crank 114. The first support 140 can extend circumferentially around the assembly axis 110 in the plane 400a. Correspondingly, the first end portions 254, 254' of the first and second pins 250, 300 can also be at the plane 400a. The second support 142 can extend circumferentially around the assembly axis 110 in the plane 400d. Correspondingly, the second end portions 256, 256' of the first and second pins 250, 300 can also be at the plane 400d. The first and second transfer members 130, 132 can be at the planes 400b, 400c, respectively. The first intermediate portions 258, 258' of the first and second pins 250, 300 can be at the plane 400b. Similarly, the second intermediate portions 260, 260' of the first and second pins 250, 300 can be at the plane 400c. Due to the circumferentially staggered arrangement of the annular recesses 262, 262', a transverse cross-sectional area of the individual first pins 250 perpendicular to the pin axis 252 can be smaller at the plane 400c than at the plane 400b and, likewise, a transverse cross-sectional area of the individual second pins 300 perpendicular to the pin axis 252' can be smaller at the plane 400b than at the plane 400c.

[0047] FIG. 12 is a perspective view of the just first and second transfer members 130, 132. FIG. 13 is an enlargement of a portion of FIG. 12. With reference now to FIGS. 1-13 together, the first transfer member 130 can include first lobes 450 and first troughs 452 circumferentially alternating around the assembly axis 110 in the plane 400b. The first lobes 450 and first troughs 452 can form a first continuous cycloidal profile through which the first transfer member 130 contacts the first pins 250 during operation of the gear assembly 112. Similarly, the second transfer member 132 can include second lobes 454 and second troughs 456 circumferentially alternating around the assembly axis 110 in the plane 400c. The second lobes 454 and second troughs 456 can form a second continuous cycloidal profile through which the second transfer member 132 contacts the second pins 300 during operation of the gear assembly 112. In other embodiments, counterparts of the first and second transfer members 130, 132 can have other suitable profiles, such as non-cycloidal and/or discontinuous profiles. With reference again to the illustrated embodiment, the gear assembly 112 can be configured to transfer torque at least primarily via contact between the first pins 250 and the first lobes 450 and via contact between the second pins 300 and the second lobes 454 as the first and second transfer members 130, 132

move out-of-phase with one another relative to the assembly axis 110 throughout a complete rotational cycle of gear assembly 112.

[0048] The alternating contact discussed above is different than a conventional rolling-contact cycloid gear assembly in which each counterpart of the first and second lobes 450, 454 engages each and every counterpart of the first and second pins 250, 300. Among other things, this difference can facilitate locating the rolling interface between the pins and the supports rather than between the pins and the transfer members. This is because, in a conventional rolling-contact cycloid gear assembly, a lobe of one transfer member and a trough of the other transfer member contact the same pin simultaneously. The lobe contact area and the trough contact area have different velocities. Rolling interfaces between the pins and the transfer members can accommodate this velocity differential whereas rolling interfaces between the pins and the supports would not. In contrast, with the alternating contact of the gear assembly 112, this limitation is reduced or eliminated such that the roller bearings 350 can be at the first and second supports 140, 142. Moreover, because the first and second supports 140, 142 have space for the sockets 210, the roller bearings 350 can be of a smaller and less expensive type (e.g., drawn-cup needle type as discussed above) than would otherwise be possible. Still further, the circumferential load distribution characteristic of the cycloid-type gearing modality is such that eliminating every other pin-to-transfer-member interface is not expected to adversely affect performance particularly when the number of pins is relatively high (e.g., greater than 15 or greater than 20). For the foregoing and/or one or more other reasons, the gear assembly 112 is expected to be more amenable to miniaturization than conventional counterparts. Moreover, the gear assembly 112 is expected to exhibit a higher torque-to-weight ratio and a higher torque-to-size ratio relative to conventional counterparts without unduly compromising backlash, efficiency, or shock resistance. Other advantages over conventional counterparts (e.g., reduced cost, reduced complexity, etc.) in addition to or instead of the foregoing advantages are also possible.

[0049] FIGS. 14, 15, 16 and 17 are, respectively, a side profile view of a pin 500, a side profile view of a pin array 501, a side profile view of a first transfer member 502, and a side profile view of a second transfer member 504 of a gear assembly of an actuator in accordance with certain additional embodiments of the present technology. In this actuator, the pin 500 can be both a counterpart of the individual first pins 250 and a counterpart of the individual second pins 300. The pins 500 can be circumferentially distributed around an assembly axis 505 and collectively arranged in the pin array 501 as a counterpart of the pin array 138. Also in this actuator, the first and second transfer members 502, 504 can be counterparts of the first and second transfer members 130, 132, respectively. As illustrated, a total number of the pins 500 in the pin array 501 can be one more than a total number of the first and second pins 250, 300 in the pin array 138. As further illustrated, peripheral profiles of the first and second transfer members 502, 504 can be significantly different than the peripheral profiles of the first and second transfer members 130, 132. Other features of the first and second transfer members 502, 504 can be generally similar to or the same as corresponding features of the first and second transfer members 130, 132. For example, although different in quantity relative to the first and second periph-

eral openings **154**, **156**, counterpart peripheral openings defined by the first and second transfer members **502**, **504** can be functionally similar to the first and second peripheral openings **154**, **156**. Furthermore, the first and second transfer members **502**, **504** can define fastener openings and voids for weight reduction as shown for the first and second transfer members **130**, **132**. Other features of the actuator can likewise be the same as or similar to corresponding features of the actuator **100**.

[0050] At a high level, the actuator corresponding to FIGS. **14-17** can cause alternating contact between the first and second transfer members **502**, **504** and the pins **500** via omitted lobes at the peripheral profiles of the first and second transfer members **502**, **504** rather than via non-uniform transverse cross-sectional areas of the pins **500**. Accordingly, as shown in FIG. **14**, the pin **500** can define a pin axis **506** and can have a uniform transverse cross-sectional area perpendicular to the pin axis **506**. As shown in FIG. **16**, the first transfer member **502** can include first lobes **508** and first troughs **510** that form a first profile through which the first transfer member **502** contacts some of the pins **500**. An average circumferential span of the first lobes **508** about a first central axis **512** defined by the first transfer member **502** can be smaller than an average circumferential span of the first troughs **510** about the first central axis **512**. Similarly, as shown in FIG. **17**, the second transfer member **504** can include second lobes **514** and second troughs **516** that form a second profile through which the second transfer member **504** contacts some of the pins **500**. An average circumferential span of the second lobes **514** about a second central axis **518** defined by the second transfer member **504** can be smaller than an average circumferential span of the second troughs **516** about the second central axis **518**. In at least some cases, an average angle **A1** (FIG. **15**) relative to the first central axis **512** between circumferentially neighboring pairs of the pins **500** is no more than one third an average angle **A2** (FIG. **16**) between circumferentially neighboring pairs of the first lobes **508**. Similarly, **A1** may be no more than one third an average angle **A3** (FIG. **17**) between circumferentially neighboring pairs of the second lobes **514**. In these and other cases, a total quantity of the first lobes **508** can be at most one third a total quantity of the pins **500**. Furthermore, a total quantity of the second lobes **514** can be at most one third a total quantity of the pins **500**. More particularly, the total quantity of the first lobes **508** and the total quantity of the second lobes **514** can individually be equal to $(P-1)/3$, where **P** is the total quantity of pins **500**.

[0051] Operating the actuator corresponding to FIGS. **14-17** can include bypassing contact between the first transfer member **502** and some of the pins **500** via the first troughs **510** and bypassing contact between the second transfer member **504** and some of the pins **500** via the second troughs **516**. In the illustrated case, the number of first lobes **508** is equal to $(P-1)/3$, where **P** is the total quantity of pins **500** in the pin array **501**. Likewise, the number of second lobes **514** is equal to $(P-1)/3$, where **P** is the total quantity of pins **500** in the pin array **501**. In particular, the pin array **501** includes 31 of the pins **500**, the first transfer member **502** includes ten of the first lobes **508**, and the second transfer member **504** includes ten of the second lobes **514**. In other cases, the counterparts of the pin array **501**, the first transfer member **502**, and the second transfer member **504** can include other suitable quantities of constituent elements circumferentially distributed evenly

about the respective axes in the same or other suitable ratios. With reference again the illustrated embodiment, it is expected that the illustrated relationships between the quantity of the first lobes **508** and the quantity of the pins **500** and between the quantity of the second lobes **514** and the quantity of the pins **500** will result in the desired alternating contact between the first and second transfer members **502**, **504** and the pins **500** without causing excessive antagonistic forces. For example, it is expected that instances of any of the pins **500** contacting both the first and second transfer members **502**, **504** simultaneously will be eliminated relative to counterparts in which the lobe-to-pin ratio is lower (e.g., about 2:1 rather than about 3:1). Counterpart embodiments in which the lobe-to-pin ratio is higher may operate with desired alternating contact, but with potentially disadvantageous reduction in load sharing. Still other embodiments can include a combination of pin nonuniformity and lobe omission.

[0052] In addition to or instead of having less than a full set of lobes, actuators in accordance with at least some embodiments of the present technology can have less than a full set of circumferential contact areas (e.g., pin and roller bearing assemblies) through which the lobes transfer torque. As an example, FIG. **18** illustrates selected components of a gear assembly of an actuator in accordance with another embodiment of the present technology. Within the gear assembly, the actuator can include an array **550** the same as or similar to an assembly of the pin array **138** and the first and second roller bearing arrays **144**, **146** of the gear assembly **112** described above. Also within the gear assembly, the actuator can include a first transfer member **552** and a second transfer member **554** operably associated with the array **550**. The first and second transfer members **552**, **554** can be similar to the first and second transfer members **130**, **132**, respectively, of the gear assembly **112** described above, but with a different circumferential edge profile such that the array **550** provides less than a full set of circumferential contact areas through which lobes of the first and second transfer members **552**, **554** transfer torque during operation of the actuator.

[0053] FIGS. **19** and **20** are side profile views of the first and second transfer members **552**, **554**, respectively. FIG. **21** is an enlargement of a portion of FIG. **20**. With reference to FIGS. **18-21** together, the first transfer member **552** can include first lobes **556** and first troughs **558** that form a first profile through which the first transfer member **552** contacts some pins of the array **550**. Similarly, the second transfer member **554** can include second lobes **560** and second troughs **562** that form a second profile through which the second transfer member **554** contacts other pins of the array **550**. As shown in FIGS. **19-21**, the first lobes **556**, first troughs **558**, second lobes **560**, and second troughs **562** can be relatively small. By way of comparison, although the pin array **138** (FIG. **3**) and the array **550** (FIG. **18**), as illustrated, each include 30 pins, the first transfer member **552**, as illustrated, includes 59 of the first lobes **556** whereas the first transfer member **130**, as illustrated, includes 29 of the first lobes **450**. Similarly, the second transfer member **554**, as illustrated, includes 59 of the second lobes **560** whereas the second transfer member **132**, as illustrated, includes 29 of the second lobes **454**. In these and other cases, the number of lobes of each transfer member can be one less than the number of pins times an integer. In the case of the actuator **100**, the integer is one, representing a full set of circumfer-

ential contact elements for a given number of lobes. In the case of the actuator corresponding to FIGS. 18-21, the integer is two. In other embodiments, the integer can be three, four, or even higher. The integer being greater than one can correspond to the presence of less than a full set of circumferential contact elements for a given number of lobes.

[0054] Partial contact in actuators in accordance with at least some embodiments of the present technology can include alternating contact and/or partial-complement contact. In alternating contact, individual circumferential contact elements (e.g., pins) transfer force via interaction with one transfer member rather than via interaction with two transfer members. In partial-complement contact, the number of circumferential contact elements is less than a full set for a given number of lobes and/or the number of lobes is less than a full set for a given number of circumferential contact elements. The actuator 100 (FIG. 1-13) exhibits alternating contact due to the configuration of the pin array 138. The actuator corresponding to FIGS. 14-17 exhibits both alternating contact and partial-complement contact due to the omitted lobes of the first and second transfer members 502, 504. Finally, the actuator corresponding to FIGS. 18-21 exhibits both alternating contact and partial-complement contact due to configuration of the array 550 and due to the edge profiles of the first and second transfer members 552, 554. Other types of partial contact as also possible

[0055] With reference again to FIGS. 18-21, the relatively small sizes of the first lobes 556, first troughs 558, second lobes 560, and second troughs 562 can be associated with direct contact of the first and second transfer members 552, 554 with pins of the array 550. The transverse diameters of the pins can be much smaller than the transverse diameters of the roller bearings of the array 550. Correspondingly, unlike the roller bearings, the pins can interact with the first and second transfer members 552, 554 directly without simultaneously contacting neighboring lobes even when the lobes and intervening troughs are relatively small. Given this size flexibility, more lobes and troughs can be included on the first and second transfer members 552, 554 without increasing the overall sizes of the first and second transfer members 552, 554. This can allow the corresponding actuator to have a higher reduction-ratio-to-size than would otherwise be possible. In at least some cases, the actuator has an input-to-output reduction ratio greater than 50:1, such as within a range from 50:1 to 70:1. Of course, high reduction ratios are not always desirable. When high reduction ratios are desirable, however, partial contact in accordance with at least some embodiments of the present technology can facilitate achieving such ratios in a more compact, light-weight, and/or robust form than was previously possible.

[0056] As discussed above, partial contact can involve partial-complement contact in addition to or instead of alternating contact. In at least some examples of partial-complement contact without alternating contact, individual pins may still interact with two transfer members yet be present in a quantity smaller than a quantity corresponding to the number of lobes. As an example, FIGS. 22 and 23 are, respectively, a perspective view and a side profile view of an assembly 570 including transfer members 572 (one labeled), pins 574 (one labeled), and roller bearings 576 (one labeled) of a gear assembly of an actuator in accordance with another embodiment of the present technology. The array 570 includes 14 of the pins 574. The transfer members 572

individually include 27 lobes. To avoid antagonistic forces, the transfer members 572 can interact with the pins 574 via the roller bearings 576 rather than directly. Relatedly, the positions of the roller bearings 576 can be incompatible with support from counterparts of the first and second supports 140, 142 (FIG. 3). Without this support, a drawn-cup configuration of the roller bearings 576 may be unsuitable.

[0057] Rather than having a drawn-cup configuration, the roller bearings 576 can have a machined-ring configuration or another suitable configuration. FIG. 24 is a front profile view of one of the roller bearings 576. FIG. 25 is a cross-sectional perspective view of the roller bearing 576 taken along the line 25-25 in FIG. 24. As shown in FIGS. 24 and 25, the roller bearing 576 can define a cylindrical cavity 578 having a diameter corresponding to a diameter of one of the pins 574. The roller bearing 576 can include rollers 580 (one labeled) aligned with and circumferentially distributed around the cylindrical cavity 578. The roller bearing 350 can further include an outer ring 582 carrying the rollers 580. The roller bearing 576 can further include a spacer 584 defining slots 586 (one labeled) in which the rollers 580 are respectively disposed. The outer ring 582 can be more robust than the cylindrical casing 358 of the roller bearing 350 (FIGS. 8-9). In at least some cases, the outer ring 582 is configured to resist hertzian contact stress and operating loads. In these and other cases, the outer ring 582 can be a tube segment having a generally consistent wall thickness.

Examples of Robot Systems

[0058] FIG. 26 is a perspective view of a mobile robot 600 including an actuator in accordance with at least some embodiments of the present technology. As shown in FIG. 26, the mobile robot 600 can include structures resembling human anatomy with respect to the features, positions, and/or other characteristics of such structures. In at least some cases, the mobile robot 600 defines a midsagittal plane about which the mobile robot 600 is bilaterally symmetrical. In these and other cases, the mobile robot 600 can be configured for bipedal locomotion similar to that of a human. Counterparts of the mobile robot 600 can have other suitable forms and features. For example, a counterpart of the mobile robot 600 can have a non-humanoid form, such as a canine form, an insectoid form, an arachnoid form, or a form with no animal analog. Furthermore a counterpart of the mobile robot 600 can be asymmetrical or have symmetry other than bilateral. Still further, a counterpart of the mobile robot 600 can be configured for non-bipedal locomotion. For example, a counterpart of the mobile robot 600 can be configured for another type of legged locomotion (e.g., quadrupedal locomotion, octopodal locomotion, etc.) and/or non-legged locomotion (e.g., wheeled locomotion, continuous-track locomotion, etc.).

[0059] The mobile robot 600 can include a centrally disposed body 602 through which other structures of the mobile robot 600 are interconnected. As all or a portion of the body 602, the mobile robot 600 can include a torso 604 having a superior portion 606, an inferior portion 608, and an intermediate portion 610 therebetween. The mobile robot 600 can further include articulated appendages carried by the torso 604. Among these articulated appendages, the mobile robot 600 can include arms 612a, 612b and legs 614a, 614b. In at least some cases, the mobile robot 600 is configured to manipulate objects via the arms 612a, 612b, such as bimanually. In these and other cases, the mobile

robot 600 can be configured to ambulate via the legs 614a, 614b, such as bipedally. The arms 612a, 612b and the legs 614a, 614b can define kinematic chains. The kinematic chains corresponding to the arms 612a, 612b, for example, can provide at least five degrees of freedom, such as exactly five or exactly six degrees of freedom. In these and other cases, the kinematic chains corresponding to the legs 614a, 614b can provide at least four degrees of freedom, such as exactly four, exactly five, or exactly six degrees of freedom. As parts of the arms 612a, 612b, the mobile robot 600 can include end effectors 616a, 616b at distalmost portions of the corresponding kinematic chains. Similarly, as parts of the legs 614a, 614b, the mobile robot 600 can include feet 618a, 618b at distalmost portions of the corresponding kinematic chains. In the illustrated embodiment, the end effectors 616a, 616b and the feet 618a, 618b are not articulated. In other embodiments, counterparts of some or all of the end effectors 616a, 616b and the feet 618a, 618b can be articulated, such as with one or more movable fingers or toes.

[0060] At the individual articulations of the arms 612a, 612b and legs 614a, 614b, the mobile robot 600 can include a joint and a corresponding actuator. At least one of these actuators can correspond to the actuator 100, the actuator corresponding to FIGS. 14-17, the actuator corresponding to FIGS. 18-21, the actuator corresponding to FIGS. 22-25, or another actuator in accordance with at least some embodiments of the present technology. For example, the mobile robot 600 can include actuators with cycloid-type gearing and partial contact (e.g., alternating contact and/or partial-complement contact) in accordance with at least some embodiments of the present technology at joints of the arms 612a, 612b, at joints of the legs 614a, 614b, and/or elsewhere. In an example, the mobile robot 600 can include elbow joints 620a, 620b at or near midpoints along lengths of the respective arms 612a, 612b. The mobile robot 600 can include actuators in accordance with at least some embodiments of the present technology at the respective elbow joints 620a, 620b. As another example, the mobile robot 600 can include foot actuators 622a-622d and connector rods 624a-624d operably associated with the feet 618a, 618b. In particular, the foot actuators 622a, 622b can be connected to the foot 618a via the connector rods 624a, 624b, respectively. Similarly, the foot actuators 622c, 622d can be connected to the foot 618b via the connector rods 624c, 624d, respectively. The mobile robot 600 can include actuators in accordance with at least some embodiments of the present technology as one, some, or all of the foot actuators 622a-622d. Actuators in accordance with at least some embodiments of the present technology can be useful in many other locations in addition or alternatively. Furthermore, the mobile robot 600 is merely one example of a system in which features of at least some embodiments of the present technology can be implemented.

Examples of Methods

[0061] FIG. 27 is a block diagram corresponding to a method 700 in accordance with at least some embodiments of the present technology. Although the method 700 will be described primarily in the context of the actuator 100, it should be understood that suitable features of the method 700 can likewise be practiced in the contexts of the actuator corresponding to FIGS. 14-17, the actuator corresponding to FIGS. 18-21, the actuator corresponding to FIGS. 22-25, or

another actuator in accordance with at least some embodiment of the present technology. With reference to FIGS. 1-27 together, the method 700 can include causing the first and second transfer members 130, 132 to move out-of-phase (e.g., 180-degrees out-of-phase) with one another about the assembly axis 110 (block 702a). This can include rotating the first and second eccentric bearings 126, 128 within the first and second central openings 134, 136, respectively. The method 700 can further include transferring force between a portion (e.g., a peripheral portion) of the first transfer member 130 and the first pins 250 (block 702b) (e.g., via a camming interaction therebetween) while the first and second transfer members 130, 132 move out-of-phase with one another about the assembly axis 110. This can include contacting the first pins 250 and the first continuous cycloidal profile defined by the first transfer member 130. Furthermore, this can include transferring force between the first lobes 450 and the first pins 250, such as by camming the first lobes 450 against the first pins 250. The contact between the first transfer member 130 and the first pins 250 can be at the first intermediate portion 258 of the first pins 250.

[0062] In at least some cases, the force transfer between the first transfer member 130 and the first pins 250 is preferential relative to force transfer (if any) between the first transfer member 130 and the second pins 300 throughout a complete rotational cycle of the gear assembly 112. The individual first pins 250 can avoid or otherwise reduce contact and/or force transfer with the second transfer member 132 while contacting and transferring force with the first transfer member 130. The lack of contact or otherwise non-preferential contact with the second transfer member 132 can be via the annular recesses 262 at the second intermediate portions 260 of the first pins 250. Relatedly, the method 700 can include maintaining clearance between the first pins 250 and the second transfer member 132 while the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. In the context of the pins 500 and the first and second transfer members 502, 504 (FIGS. 14-17), the pins 500 can include counterparts of the first pins 250 that avoid or otherwise reduce contact and/or force transfer with the second transfer member 504 while contacting and transferring force with the first transfer member 502. The lack of contact or otherwise non-preferential contact with the second transfer member 504 can be via the second troughs 516. Relatedly, the method 700 can include maintaining clearance between the counterparts of the first pins 250 and the second transfer member 504 while the first and second transfer members 502, 504 move out-of-phase with one another relative to the assembly axis 110.

[0063] The method 700 can also include transferring force between a portion (e.g., a peripheral portion) of the second transfer member 132 and the second pins 300 (block 702c) (e.g., via a camming interaction therebetween) while the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. This can include contacting the second pins 300 and the second continuous cycloidal profile defined by the second transfer member 132. Furthermore, this can include transferring force between the second lobes 454 and the second pins 300, such as by camming the second lobes 454 against the second pins 300. The contact between the second transfer member 132 and the second pins 300 can be at the second intermediate portions 260' of the second pins 300.

[0064] In at least some cases, the force transfer between the second transfer member 132 and the second pins 300 is preferential relative to force transfer (if any) between the second transfer member 132 and the first pins 250 throughout a complete rotational cycle of the gear assembly 112. The individual second pins 300 can avoid or otherwise reduce contact and/or force transfer with the first transfer member 130 while contacting and transferring force with the second transfer member 132. The lack of contact or otherwise non-preferential contact with the first transfer member 130 can be via the annular recesses 262' at the first intermediate portions 258' of the second pins 300. Relatedly, the method 700 can include maintaining clearance between the second pins 300 and the first transfer member 130 while the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. In the context of the pins 500 and the first and second transfer members 502, 504 (FIGS. 14-17), the pins 500 can include counterparts of the second pins 300 that avoid or otherwise reduce contact and/or force transfer with the first transfer member 502 while contacting and transferring force with the second transfer member 504. The lack of contact or otherwise non-preferential contact with the first transfer member 502 can be via the first troughs 510. Relatedly, the method 700 can include maintaining clearance between the counterparts of the second pins 300 and the first transfer member 502 while the first and second transfer members 502, 504 move out-of-phase with one another relative to the assembly axis 110.

[0065] In connection with the force transfer between the first transfer member 130 and the first pins 250 and the force transfer between the second transfer member 132 and the second pins 300, the method 700 can include causing rotation of the individual first and second pins 250, 300 relative to the first and second supports 140, 142 while the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. In these and/or other cases, the method 700 can include rotatably carrying the first end portions 254, 254' of the individual first and second pins 250, 300 at respective ones of the roller bearings 350 at the first support 140 while the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. The method 700 can further include carrying the roller bearings 350 of the first roller bearing array 144 at the sockets 210 of the first support 140 and/or at the through holes 208 of the plate 200 of the first support 140 while the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. Likewise, the method 700 can include rotatably carrying the second end portions 256, 256' of the individual first and second pins 250, 300 at respective ones of the roller bearings 350 at the second support 142 while the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. The method 700 can further include carrying the roller bearings 350 of the second roller bearing array 146 at the sockets 210' of the second support 142 and/or at the through holes 208' of the plate 200' of the second support 142 while the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110. The method 700 can further include directly contacting the first and second pins 250, 300 and the cylindrical outer surfaces 368 of the rollers

354 while the first and second transfer members 130, 132 move out-of-phase with one another relative to the assembly axis 110.

[0066] Finally, the method 700 can include rotating an output member (block 702d), such as the crank 114. This too can occur while causing the first and second transfer members 130, 132 to move out-of-phase with one another relative to the assembly axis 110. In some cases, rotating the output member is relative to a mount. For example, the link 104 (FIG. 2) can be a mount relative to which actuator 100 rotates the crank 114. In these and other cases, rotating the output member can be in response to force exerted by the first and second transfer members 130, 132 against the base 150 via the rods 152. Alternatively or in addition, the method 700 can include operating the actuator 100 in the opposite direction. For example, the method 700 can include rotating the first and second supports 140, 142 relative to a mount in response to force exerted by the first and second transfer members 130, 132 against the first and second supports 140, 142 via the first and second pins 250, 300. Regardless of the direction, operating the actuator 100 can cause an input-to-output reduction ratio. In at least some cases, the method 700 includes causing an input-to-output reduction ratio within a range from 20:1 to 40:1, such as from 25:1 to 35:1, via the gear assembly 112 or another gear assembly in accordance with at least some embodiments of the present technology. Similarly, the method 700 can include causing an input-to-output reduction ratio greater than 50:1, such as within a range from 50:1 to 70:1, via the gear assembly corresponding to FIGS. 18-21 or another gear assembly in accordance with at least some embodiments of the present technology.

Conclusion

[0067] This disclosure is not intended to be exhaustive or to limit the present technology to the precise forms disclosed herein. Although specific embodiments are disclosed herein for illustrative purposes, various equivalent modifications are possible without deviating from the present technology, as those of ordinary skill in the relevant art will recognize. In some cases, well-known structures and functions have not been shown or described in detail to avoid unnecessarily obscuring the description of the embodiments of the present technology. Although steps of methods may be presented herein in a particular order, in alternative embodiments the steps may have another suitable order. Similarly, certain aspects of the present technology disclosed in the context of particular embodiments can be combined or eliminated in other embodiments. Furthermore, while advantages associated with certain embodiments may be disclosed herein in the context of those embodiments, other embodiments may also exhibit such advantages, and not all embodiments need necessarily exhibit such advantages or other advantages disclosed herein to fall within the scope of the present technology. This disclosure and the associated technology can encompass other embodiments not expressly shown or described herein.

[0068] Throughout this disclosure, the singular terms “a,” “an,” and “the” include plural referents unless the context clearly indicates otherwise. Similarly, unless the word “or” is expressly limited to mean only a single item exclusive from the other items in reference to a list of two or more items, then the use of “or” in such a list is to be interpreted as including (a) any single item in the list, (b) all of the items in the list, or (c) any combination of the items in the list. As

used herein, the terms “generally,” “substantially,” “about,” and similar terms are used as terms of approximation and not as terms of degree, and are intended to account for the inherent variations in measured or calculated values that would be recognized by those of ordinary skill in the art. Additionally, the terms “comprising,” “including,” “having,” and the like are used throughout this disclosure to mean including at least the recited feature(s) such that any greater number of the same feature(s) and/or one or more additional types of features are not precluded. This is the case even if a particular number of features is specified unless that specified number is preceded by the word “exactly” or another clear indication that it is intended to be closed ended. In a particular example, “comprising two arms” means including at least two arms. References herein to any of receiving, determining, or generating information in accordance with various embodiments of the present technology encompass, when feasible, the others of receiving, determining, and generating the information and indicate that such operations can occur at least partially via the relevant computing subsystem.

[0069] Directional terms, such as “upper,” “lower,” “front,” “back,” “vertical,” and “horizontal,” may be used herein to express and clarify the relationship between various structures. It should be understood that such terms do not denote absolute orientation. Reference herein to “one embodiment,” “an embodiment,” or similar phrases means that a particular feature, structure, or operation described in connection with such phrases can be included in at least one embodiment of the present technology. Thus, such phrases as used herein are not all referring to the same embodiment. Unless preceded with the word “conventional,” reference herein to “counterpart” devices, systems, methods, features, structures, or operations refers to devices, systems, methods, features, structures, or operations in accordance with at least some embodiments of the present technology that are similar to a described device, system, method, feature, structure, or operation in certain respects and different in other respects. Finally, it should be noted that various particular features, structures, and operations of the embodiments described herein may be combined in any suitable manner in additional embodiments in accordance with the present technology.

1. A gear assembly comprising:

- a first support extending circumferentially around an assembly axis in a first plane intersecting the assembly axis;
- a second support extending circumferentially around the assembly axis in a second plane intersecting the assembly axis, wherein the first and second planes are spaced apart from one another along the assembly axis;
- a first transfer member including first lobes and first troughs circumferentially alternating in a third plane intersecting the assembly axis, wherein the third plane is between the first and second planes along the assembly axis;
- a second transfer member including second lobes and second troughs circumferentially alternating in a fourth plane intersecting the assembly axis, wherein the fourth plane is between the first and third planes along the assembly axis; and
- pins individually extending between the first and second supports along respective pin axes, wherein the individual pins are configured to rotate relative to the first

and second supports about the respective pin axes in response to force from at least one of the first and second transfer members during operation of the gear assembly as the first and second transfer members move out-of-phase with one another relative to the assembly axis,

wherein a total quantity of the first lobes is at least two times a total quantity of the pins minus one, and wherein a total quantity of the second lobes is at least two times the total quantity of the pins minus one.

2. The gear assembly of claim 1, wherein:

the total quantity of the first lobes is three times the total quantity of the pins minus one; and
the total quantity of the second lobes is three times the total quantity of the pins minus one.

3. The gear assembly of claim 1, wherein the individual pins directly contact one of the first and second transfer members and remain out of contact with the other of the first and second transfer members during operation of the gear assembly as the first and second transfer members move out-of-phase with one another relative to the assembly axis.

4. A gear assembly comprising:

- a first support extending circumferentially around an assembly axis in a first plane intersecting the assembly axis;
- a second support extending circumferentially around the assembly axis in a second plane intersecting the assembly axis, wherein the first and second planes are spaced apart from one another along the assembly axis;
- a first transfer member including first lobes and first troughs circumferentially alternating in a third plane intersecting the assembly axis, wherein the third plane is between the first and second planes along the assembly axis;
- a second transfer member including second lobes and second troughs circumferentially alternating in a fourth plane intersecting the assembly axis, wherein the fourth plane is between the first and third planes along the assembly axis;
- pins individually extending between the first and second supports along respective pin axes;
- first roller bearings circumferentially distributed around the assembly axis at the third plane; and
- second roller bearings circumferentially distributed around the assembly axis at the fourth plane,

wherein:

- the pins indirectly contact the first transfer member via the first roller bearings, and
- the pins indirectly contact the second transfer member via the second roller bearings,
- a total quantity of the first lobes is at least two times a total quantity of the pins minus one, and
- a total quantity of the second lobes is at least two times the total quantity of the pins minus one.

5. The gear assembly of claim 1, wherein:

the first and second pins are at respective positions circumferentially alternating about the assembly axis; and

the gear assembly is configured to transfer torque at least primarily via contact between the first pins and the first lobes and via contact between the second pins and the second lobes as the first and second transfer members move out-of-phase with one another relative to the assembly axis.

6. The gear assembly of claim 1, wherein:
the gear assembly further comprises:
first roller bearings at the first support, and
second roller bearings at the second support; and
the pins individually extend between different respective
pairs of one of the first roller bearings and one of the
second roller bearings.
7. The gear assembly of claim 6, wherein:
the first support includes first sockets circumferentially
distributed around the assembly axis;
the first roller bearings are at least partially disposed
within the first sockets;
the second support includes second sockets circumferentially
distributed around the assembly axis; and
the second roller bearings are at least partially disposed
within the second sockets.
8. The gear assembly of claim 7, wherein:
the first support includes a first plate defining first through
holes;
the first sockets are at the first through holes;
the second support includes a second plate defining second
through holes; and
the second sockets are at the second through holes.
9. The gear assembly of claim 6, wherein the first and
second roller bearings are drawn-cup needle roller bearings.
10. The gear assembly of claim 1, wherein:
the pins include:
first pins that remain out of contact with the second
transfer member during operation of the gear assembly as the first and second transfer members move
out-of-phase with one another relative to the assembly axis, and
second pins that remain out of contact with the first
transfer member during operation of the gear assembly as the first and second transfer members move
out-of-phase with one another relative to the assembly axis; and
the individual first and second pins are elongate and have
a non-uniform transverse cross-sectional area along the
corresponding pin axis.
11. The gear assembly of claim 12, wherein:
a transverse cross-sectional area of the individual first
pins is smaller at the fourth plane than at the third
plane; and
a transverse cross-sectional area of the individual second
pins is smaller at the third plane than at the fourth plane.
12. A gear assembly comprising:
a first support extending circumferentially around an
assembly axis in a first plane intersecting the assembly axis;
a second support extending circumferentially around the
assembly axis in a second plane intersecting the assembly axis, wherein the first and second planes are spaced
apart from one another along the assembly axis;
a first transfer member including first lobes and first
troughs circumferentially alternating in a third plane
intersecting the assembly axis, wherein the third plane
is between the first and second planes along the assembly axis;
a second transfer member including second lobes and
second troughs circumferentially alternating in a fourth
plane intersecting the assembly axis, wherein the fourth
plane is between the first and third planes along the
assembly axis; and

pins individually extending between the first and second
supports along respective pin axes, wherein the individual pins are configured to rotate relative to the first
and second supports about the respective pin axes in
response to force from at least one of the first and
second transfer members during operation of the gear
assembly as the first and second transfer members
move out-of-phase with one another relative to the
assembly axis,

wherein:

the pins include:

first pins that remain out of contact with the second
transfer member during operation of the gear
assembly as the first and second transfer members
move out-of-phase with one another relative to the
assembly axis, and

second pins that remain out of contact with the first
transfer member during operation of the gear
assembly as the first and second transfer members
move out-of-phase with one another relative to the
assembly axis; and

the individual first and second pins are elongate and
have a non-uniform transverse cross-sectional area
along the corresponding pin axis,

a total quantity of the first lobes is at least two times a
total quantity of the pins minus one,

a total quantity of the second lobes is at least two times
the total quantity of the pins minus one,

the individual first and second pins include:

a first end portion at the first support,

a second end portion at the second support,

a first intermediate portion between the first and
second end portions, and

a second intermediate portion between the first intermediate
portion and the second end portion,

the individual first pins are configured to contact the
first transfer member via the first intermediate portion, and

the individual second pins are configured to contact the
second transfer member via the second intermediate
portion.

13. The gear assembly of claim 12, wherein:

the individual first pins include a first annular recess at the
second intermediate portion; and

the individual second pins include a second annular recess
at the first intermediate portion.

14. The gear assembly of claim 12, wherein:

the first lobes and first troughs form a first continuous
cycloidal profile through which the first transfer member
contacts the first pins; and

the second lobes and second troughs form a second
continuous cycloidal profile through which the second
transfer member contacts the second pins.

15. The gear assembly of claim 12, wherein a distribution
of the first and second pins around the assembly axis is
radially symmetrical.

16. The gear assembly of claim 1, wherein:

the gear assembly further comprises a carrier including a
base and rods individually extending from the base;

the first transfer member defines first peripheral openings
distributed circumferentially around the assembly axis;

the second transfer member defines second peripheral
openings distributed circumferentially around the
assembly axis; and

the individual rods extend through different respective pairs of one of the first peripheral openings and one of the second peripheral openings.

17. The gear assembly of claim **16**, wherein:

the gear assembly further comprises:

a mount fixedly connected to the first and second supports, and

an output member fixedly connected to the base; and

the gear assembly is configured to rotate the output member relative to the mount in response to force exerted by the first and second transfer members against the base via the rods.

18. The gear assembly of claim **16**, wherein:

the gear assembly further comprises a mount fixedly connected to the base; and

the gear assembly is configured to rotate the first and second supports relative to the mount in response to

force exerted by the first and second transfer members against the first and second supports via the pins.

19. The gear assembly of claim **1**, further comprising: an input shaft configured to rotate about the assembly axis; and

a first eccentric bearing carried by the input shaft, wherein the first transfer member defines a first central opening at which the first eccentric bearing is rotatably disposed; and

a second eccentric bearing carried by the input shaft, wherein the second transfer member defines a second central opening at which the second eccentric bearing is rotatably disposed.

20. The gear assembly of claim **1**, wherein the gear assembly has an input-to-output reduction ratio within a range from 50:1 to 70:1.

* * * * *