United States Patent Application Publication	20250250971
Kind Code	A1
Publication Date	August 07, 2025
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AXIAL PUMP ASSEMBLIES

Abstract

An axial pump assembly for a hydraulic tool includes a cycloidal disk rotatable about an axis and having an eccentric opening configured to receive a rotational input. A ring defines a cam track and is engaged with the cycloidal disk so that rotation of the cycloidal disk causes corresponding rotation of the ring about the axis. A plate includes a follower that engages with the cam track so that rotation of the cam track causes corresponding reciprocating motion of the plate along the axis.

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Family ID: **71995116**

Appl. No.: **19/187747**

Filed: **April 23, 2025**

Related U.S. Application Data

parent US division 18331679 20230608 parent-grant-document US 12313046 child US 19187747
parent US division 17867207 20220718 parent-grant-document US 11708821 child US 18331679
parent US division 16931637 20200717 parent-grant-document US 11421665 child US 17867207
us-provisional-application US 62875069 20190717

Publication Classification

Int. Cl.: **F04B1/043** (20200101); **F04B1/0413** (20200101)

U.S. Cl.:

CPC **F04B1/043** (20130101); **F04B1/0413** (20130101);

Background/Summary

RELATED APPLICATIONS [0001] This application is a divisional application of U.S. patent application Ser. No. 18/331,679, filed Jun. 8, 2023, which is a divisional of U.S. patent application Ser. No. 17/867,207, filed Jul. 18, 2022, which is a divisional of U.S. patent application Ser. No. 16/931,637, filed Jul. 17, 2020, which claims priority to U.S. Provisional Application No. 62/875,069, filed Jul. 17, 2019, the contents of which are incorporated herein by reference in their entireties.

BACKGROUND

[0002] The present disclosure relates generally to power tools. M ore particularly, the present disclosure relates to axial pump designs for a hydraulic power tool.

[0003] Hydraulic crimpers and cutters are different types of hydraulic power tools for performing work (e.g., crimping or cutting) on a workpiece. In such tools, a hydraulic tool comprising a hydraulic pump is utilized for pressurizing hydraulic fluid and transferring it to a cylinder in the tool. This cylinder causes an extendible piston to be displaced towards a cutting or crimping head. The piston exerts a force on the head of the power tool, which may typically include opposed jaws with certain cutting or crimping features, depending upon the particular configuration of the power tool. In this case, the force exerted by the piston may be used for closing the jaws to perform cutting or crimping on a workpiece (e.g., a wire) at a targeted location.

[0004] In some known hydraulic tools, a motor can drive the hydraulic pump by way of a gear reducer or other type of gear assembly. However, there are certain perceived disadvantages to such known hydraulic tools. For example, the motor, hydraulic pump (e.g., one or more pump pistons), and gear assembly can often be complex, heavy, and bulky, particularly in hydraulic tools that are designed for high force applications. In some cases, this can increase the cost to manufacture the hydraulic tool and might make the hydraulic tool more cumbersome for an operator to use.

[0005] Therefore, it may be useful to provide a less complex, lighter weight hydraulic tool that can be used for high force applications or lower force applications and that is also more user friendly to the operator.

SUMMARY

[0006] According to one aspect of the present disclosure, an axial pump assembly for a hydraulic tool can include a cycloidal disk rotatable about an axis and having an eccentric opening configured to receive a rotational input. The assembly can include a ring defining a cam track, where the ring can be engaged with the cycloidal disk so that rotation of the cycloidal disk causes corresponding rotation of the ring about the axis. The assembly can also include a plate having a follower that engages with the cam track so that rotation of the cam track causes corresponding reciprocating motion of the plate along the axis.

[0007] In some examples, the cycloidal disk can define a geared periphery and the ring can include a plurality of pins that engage with the geared periphery to transmit rotation of the cycloidal disk to the ring.

[0008] In some examples, the eccentric opening can be defined by a bushing that is received in a central opening defined in the cycloidal disk.

[0009] In some examples, a plurality of pins can extend between the cycloidal disk and the plate.

[0010] In some examples, the ring can rotate relative to each of the cycloidal disk and the plate.

[0011] In some examples, the plurality of pins can extend through the ring.

[0012] In some examples, the cycloidal disk can include a plurality of holes arranged around the eccentric opening to receive the plurality of pins.

[0013] In some examples, the assembly can further include a plurality of bushings that are positioned in the plurality of holes and receive the plurality of pins.

[0014] In some examples, the assembly can further include a base that includes the plurality of pins.
[0015] In some examples, the base can define a recess that receives each of the cycloidal disk, the ring, and the plate.
[0016] In some examples, the assembly can further include a bearing that is positioned between the ring and a sidewall of the base.
[0017] According to another aspect of the present disclosure, an axial pump assembly for a hydraulic tool can include a rotational input extending along and rotatable about an axis. The assembly can include a cycloidal disk having an eccentric opening that receives the rotational input so that rotation of the rotational input causes rotation of the cycloidal disk about the axis, and the cycloidal disk can further define a plurality of holes arranged around the eccentric opening. The assembly can include a cam rotated by the cycloidal disk about the axis, and a plate that engages with the cam so that rotation of the cam causes corresponding reciprocating motion of the plate along the axis. The assembly can also include a base including a first plurality of pins that extend along the axis and through the plurality of holes in the cycloidal disk to the plate so that the plate is rotationally fixed to the base.
[0018] In some examples, the assembly can further include a bearing positioned between the base and the cam.
[0019] In some examples, the cam can rotate at a reduced speed relative to the rotational input.
[0020] In some examples, the cycloidal disk can define a geared periphery that engages with a second plurality of pins extending away from the cam.
[0021] In some examples, the plate can be engaged with the cam via follower bushings.
[0022] In some examples, the rotational input can be a shaft of a motor that extends through the base to the eccentric opening.
[0023] In some examples, the eccentric opening can be defined in an eccentric bushing that is received in a central opening of the cycloidal disk, and a plurality of bushings can be positioned in the plurality of holes to be between the first plurality of pins and the cycloidal disk.
[0024] According to yet another aspect of the present disclosure, a method of operating an axial pump assembly can include driving a cycloidal disk via a rotational input that is received in an eccentric opening of the cycloidal disk, where the rotational input defines an axis of rotation. The method can include rotating a cam about the axis of rotation with the cycloidal disk, and reciprocating a plate that is engaged with the cam so that rotation of the cam causes corresponding reciprocating motion of the plate along the axis of rotation.
[0025] In some examples, the cam can rotate at a reduced speed relative to the rotational input.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0026] The accompanying drawings, which are incorporated in and form a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of embodiments of the invention:
[0027] FIG. **1**A illustrates an exploded view of an axial pump assembly according to one embodiment of the invention.
[0028] FIG. **1**B is a cross-sectional top-down view of the axial pump assembly of FIG. **1**A in a retracted position.
[0029] FIG. **1**C is a cross-sectional top-down view of the axial pump assembly of FIG. **1**A in an extended position.
[0030] FIG. **1**D is a corner-sectioned view of the axial pump assembly of FIG. **1**A in the retracted position.

[0031] FIG. **1**E is a corner-sectioned view of the axial pump assembly of FIG. **1**A in the extended position.
[0032] FIG. **1**F is a cross-sectional side view of the axial pump assembly of FIG. **1**A operatively coupled to a pump piston and a motor shaft.
[0033] FIG. **2**A is an exploded view of an axial pump assembly according to another embodiment of the invention.
[0034] FIG. **2**B is a corner-sectioned view of the axial pump assembly of FIG. **2**A in a retracted position.
[0035] FIG. **2**C is a corner-sectioned view of the axial pump assembly of FIG. **2**A in an extended position.
[0036] FIG. **2**D is a cross-sectional side view of the axial pump assembly of FIG. **2**A operatively coupled to a pump piston and a gearbox.
[0037] FIG. **3**A is an exploded view of an axial pump assembly according to another embodiment of the invention.
[0038] FIG. **3**B is a perspective view of a bottom of a reciprocating disk of the axial pump assembly of FIG. **3**A.
[0039] FIG. **3**C is a cross-sectional view of the axial pump assembly of FIG. **3**A in a retracted position.
[0040] FIG. **3**D is a cross-sectional view of the axial pump assembly of FIG. **3**A in an extended position.
[0041] FIG. **3**E is a cross-sectional side view of the axial pump assembly of FIG. **3**A operatively coupled to a pump piston and a motor shaft.
[0042] FIG. **4**A is an exploded view of an axial pump assembly according to another embodiment of the invention.
[0043] FIG. **4**B is a perspective view of a bottom of a reciprocating disk of the axial pump assembly of FIG. **4**A.
[0044] FIG. **4**C is a cross-sectional view of the axial pump assembly of FIG. **4**A in a retracted position.
[0045] FIG. **4**D is a cross-sectional view of the axial pump assembly of FIG. **4**A in an extended position.
[0046] FIG. **4**E is a cross-sectional side view of the axial pump assembly of FIG. **4**A operatively coupled to a pump piston and a motor shaft.
[0047] FIG. **5**A is an exploded view of an axial pump assembly according to another embodiment of the invention.
[0048] FIG. **5**B is a perspective view of the axial pump assembly of FIG. **5**A in a retracted position.
[0049] FIG. **5**C is a perspective view of the axial pump assembly of FIG. **5**A in an extended position.
[0050] FIG. **5**D is a cross-sectional side view of the axial pump assembly of FIG. **5**A operatively coupled to a pump piston and a motor shaft.
[0051] FIG. **6**A is an exploded view of an axial pump assembly according to another embodiment of the invention.
[0052] FIG. **6**B is a perspective view of the axial pump assembly of FIG. **6**A in a retracted position.
[0053] FIG. **6**C is a perspective view of the axial pump assembly of FIG. **6**A in an extended position.
[0054] FIG. **6**D is a cross-sectional side view of the axial pump assembly of FIG. **6**A operatively coupled to a motor shaft.
[0055] FIG. **7**A is an exploded view of an axial pump assembly according to another embodiment of the invention.
[0056] FIG. **7**B is a perspective view of the axial pump assembly of FIG. **7**A in a retracted position.
[0057] FIG. **7**C is a perspective view of the axial pump assembly of FIG. **7**A in an extended

position.
[0058] FIG. 7D is a cross-sectional side view of the axial pump assembly of FIG. 7A operatively coupled to a motor shaft.
DETAILED DESCRIPTION
[0059] The following discussion is presented to enable a person skilled in the art to make and use embodiments of the invention. Various modifications to the illustrated embodiments will be readily apparent to those skilled in the art, and the generic principles herein can be applied to other embodiments and applications without departing from embodiments of the invention. Thus, embodiments of the invention are not intended to be limited to embodiments shown, but are to be accorded the widest scope consistent with the principles and features disclosed herein. The following detailed description is to be read with reference to the figures, in which like elements in different figures have like reference numerals. The figures, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of embodiments of the invention. Skilled artisans will recognize the examples provided herein have many useful alternatives and fall within the scope of embodiments of the invention.
[0060] As used herein, unless specified or limited otherwise, the terms “mounted,” “connected,” “supported,” and “coupled” and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, “connected” and “coupled” are not restricted to physical or mechanical connections or couplings.
[0061] The disclosed axial pump assembly will be described with respect to an example hydraulic tool. However, any one or more example embodiments of the disclosed axial pump assembly could be incorporated in alternate forms of a hydraulic tool. Furthermore, one or more example embodiments of the disclosed axial pump assembly could be used outside of the context of a pump system, and could more generally be used as a mechanism or mechanisms that generate/generates reciprocation.
[0062] In example embodiments, the disclosed axial pump assembly can be part of a transmission end of a hydraulic power tool. The transmission end of the hydraulic tool can include an electric motor configured to drive the axial pump assembly to cause a pump piston to reciprocate up and down. In practice, the movement of the pump piston can provide hydraulic fluid to a hydraulic fluid passage circuit. Specifically, as the pump piston moves down, hydraulic fluid can be withdrawn from a bladder or other device, and as the pump piston moves upward, the withdrawn fluid can be pressurized and delivered by way of the fluid passage circuit to a ram assembly of the hydraulic power tool, in order to drive a cutting or crimping head of the hydraulic power tool to perform a cutting or crimping action on a workpiece or other target.
[0063] In example embodiments, the axial pump assembly can include a reciprocating element, such as a block, a plate, or a disk, that can be operatively coupled to the pump piston. In an alternative arrangement, the pump piston and the reciprocating element can comprise an integral component. The axial pump assembly can also include a drive element, such as a cycloidal disk or other structure, configured to drive movement of the reciprocating element. In some embodiments, the drive element can include its own internal speed reduction, eliminating the need for a gear reducer assembly. The axial pump assembly can also include one or more ball or bearing elements arranged between the drive element and the reciprocating element so that motion and force applied to the driver causes movement of the ball or bearing elements, which in turn causes movement of the reciprocating element. The axial pump assembly can also include a base that provides a housing for one or more other components of the axial pump assembly, such as the one or more ball or bearing elements and the drive element. In some embodiments, the base can be part of or inserted into a gearbox of the transmission end of the hydraulic tool.
[0064] Each of the example embodiments of the disclosed axial pump assembly described herein generate reciprocating motion of the reciprocating element (and thus the pump piston) in a different way and provides an advantage over pump designs in existing tools. For example, the embodiments

can be compact (i.e., a smaller form factor) and can reduce the quantity of components needed to achieve desired reciprocating motion. Some embodiments can include components that enable internal speed reduction, eliminating or reducing the need for an external gear reduction assembly. Additionally, in some embodiments, the reciprocating element and the drive element can be arranged, and can operate, about a common axis, and the reciprocating element and the pump piston can be substantially in line with the motor of the hydraulic tool. In other words, the axial pump assembly enables a shaft of the motor to be substantially coaxial to the line of action of the pump piston that is operatively coupled to the reciprocating element (and thus substantially coaxial to the line of action of the reciprocating element). By having components of the axial pump assembly in line with the motor, the size and complexity of the transmission end of the hydraulic tool can be reduced. In some embodiments, the pump piston can be arranged about the same common axis as the reciprocating element and the drive element. Further, in some embodiments, even more components of the axial pump assembly can be arranged about the same common axis.

[0065] FIG. **1**A illustrates an axial pump assembly **100** that uses radial movement of ball elements **108** to drive a pump piston **118** (see, for example FIG. **1**F). The axial pump assembly **100** includes a reciprocating block **102**, a sun driver **104**, planetary elements **106**, ball elements **108**, and a base **110**. The reciprocating block **102** can be coupled to the pump piston **118** by way of a compression spring **112**, where the compression spring **112** can be used to provide force to retract the axial pump assembly **100**. Further, the compression spring **112** can push the axial pump assembly **100** together, helping to hold the pump assembly **100** together.

[0066] The reciprocating block **102** includes four ramped radial channels **114** that extend radially outward from an inner circumferential surface **113** of the reciprocating block **102**. Each channel **114** can take the form of a through-hole or a blind hole. As a representative example, a single ramped radial channel **114** is labeled in FIG. **1**A. In some examples, each channel **114** can be ramped downward (i.e., toward the base **110**, rather than toward a top surface of the reciprocating block **102**, as shown).

[0067] The sun driver **104** is a cylindrical-shaped element that functions as a rotational input and can be operatively coupled (e.g., pressed) directly to a shaft **120** (see, for example, FIG. **1**F) of a motor of a hydraulic tool through a bottom of the base **110**. The sun driver **104** can include a race portion **104**A and a geared portion **104**B. The race portion **104**A is a portion of the sun driver **104** on which race portions **106**A of the planetary elements **106** roll. The geared portion **104**B is a portion of the sun driver **104** that meshes with geared portions **106**B of the planetary elements **106**, creating a planetary speed reducing system. In some embodiments, the sun driver **104** does not include a race portion **104**A, but the planetary elements **106** can still roll (i.e., rotate) around the sun driver **104** about a longitudinal axis **122** of the sun driver **104**.

[0068] The planetary elements **106** are cylindrical-shaped elements, each having a respective race portion **106**A and a respective geared portion **106**B. The race portion **106**A is a portion of the planetary element **106** on which the ball elements **108** roll. The geared portion **106**B functions as a planetary gear for speed reduction. As noted above, the geared portions **106**B of the planetary elements **106** mesh with the gear portion of the sun driver **104**. The ball elements **108** can be spherical objects made of metal or another material.

[0069] The base **110** can be a housing that encircles and at least partially encloses the sun driver **104**, the planetary elements **106**, and the ball elements **108**. Further, a cylindrical portion **109** of the base **110** can include four through-holes **116** that are each separated by a prescribed distance to space out the ball elements **108**. As a representative example, a single through-hole **116** is labeled in FIG. **1**A. An inner circumferential surface **107** of the base **110** can, in some embodiments, include a geared portion **111** that meshes with the geared portions **106**B of the planetary elements **106** for the purposes of speed reduction. As shown, the base **110** has a peripheral flange **115** against which an end **117** of the reciprocating block **102** can rest or be adjacently positioned when the reciprocating block **102** is in a retracted position, as illustrated in FIGS. **1**B and **1**D, for example.

[0070] Although four ramped radial channels **114** and four ball elements **108** are shown, alternative embodiments of the axial pump assembly **100** can include more or less of the same or similar channels and ball elements. For example, some embodiments can include two ball elements and two corresponding ramped radial channels similar to the ball elements **108** and ramped radial channels **114** of the axial pump assembly **100**.
[0071] In operation, the motor rotates the sun driver **104** within the cylindrical portion **109** of the base **110**, causing rotation of the planetary elements **106** about the sun driver **104** (i.e., about the longitudinal axis **122** of the axial pump assembly **100**). Rotation of the planetary elements **106** pushes the ball elements **108** radially outward into the ramped radial channels **114** of the reciprocating block **102**. The inner circumferential surface **113** of the reciprocating block **102** surrounds the cylindrical portion **109** of the base **110**. The ball elements **108** are pushed against the ramped surfaces within the channels **114** at the through-holes **116**, pushing the reciprocating block **102** upwards in a direction substantially parallel to the longitudinal axis **122** and the end **117** of the reciprocating block **102** is moved away from the peripheral flange **115** of the base **110**. This motion can thus push the pump piston **118** upward. Following this motion, the ball elements **108** retract radially inward within the ramped radial channels **114**, toward the sun driver **104**, bringing the reciprocating block **102** downwards. As arranged in the manner shown in FIG. **1**A, each of the ball elements **108** can move radially outward at substantially the same time as one another, and can also retract radially inward at substantially the same time as one another. In this way, the ramped radial channels **114** act as cams and the ball elements **108** act as cam followers.
[0072] FIG. **1**B is a cross-sectional top-down view of the axial pump assembly **100** in the retracted position. In the retracted position, the ball elements **108** are retracted into the ramped radial channels **114**. In the retracted position, a single ball element **108** can be in contact with one or more planetary elements **106**. The ball elements **108** are positioned radially inward and proximate to one end of the ramped radial channels **114** adjacent to the inner circumferential surface **113** of the block reciprocating block **102**. Thus, the reciprocating block **102** is in a downward position and the end **117** of the reciprocating block **102** is adjacent to the peripheral flange **115** of the base **110**. Force from the compression spring **112** can bias the axial pump assembly **100** in the retracted position.
[0073] FIG. **1**C is a cross-sectional top-down view of the axial pump assembly **100** in an extended position. In the extended position, the ball elements **108** are pushed radially outward and away from the inner circumferential surface **113** of the reciprocating block **102** and into the ramped radial channels **114**. In the extended position, a single ball element **108** is in contact with a single planetary element **106**. As the ball elements engage the ramp of the ramped radial channels **114**, the reciprocating block **102** is moved upward and the end **117** of the reciprocating block **102** is moved away from the peripheral flange **115** of the base **110**. Thus, the reciprocating block **102** is in an upward, and extended position.
[0074] FIGS. **1**D and **1**E further illustrate the relative position of the planetary elements **106** and the ball elements **108** with respect to the ramped radial channels **114**. FIG. **1**D is a corner-sectioned view of the axial pump assembly **100** in the retracted position. FIG. **1**E is a corner-sectioned view of the axial pump assembly **100** in the extended position.
[0075] FIG. **1**F is a cross-sectional side view of the axial pump assembly **100** where the axial pump assembly **100** is operatively coupled to the pump piston **118** and the motor shaft **120**. The sun driver **104** of the axial pump assembly **100** can be operatively coupled to the motor shaft **120**. Although a compression spring is not illustrated in FIG. **1**F, the schematic representation of the pump piston **118** can include both the compression spring **112** of FIG. **1**A and the pump piston **118**. Further, FIG. **1**F illustrates the axial pump assembly **100**, the pump piston **118**, and the motor shaft **120** are arranged about the longitudinal axis **122**.
[0076] An advantage of the axial pump assembly **100** is that it combines mechanisms for reciprocation and speed reduction into a single compact system. This is accomplished by combining diameters of planetary gears (i.e., planetary elements **106**) as both speed reducers and

cams. Another advantage of the axial pump assembly **100** is that one set of cam follower elements (i.e., ball elements **108** of FIG. **1**A) drive motion that is perpendicular to the axis of the motor shaft **120** (i.e., axis **122**)—namely, the radial movement of the ball elements **108** of FIG. **1**A—and also drive reciprocating motion that is in line with axis **122** (i.e., motion of the reciprocating block **102** of FIG. **1**A and the pump piston **118** of FIG. **1**F). Further, another advantage of the axial pump assembly **100** is that the arrangement of the axial pump assembly **100** enables the motor shaft **120** to be coaxial to the line of action of the pump piston **118**, which can help provide stable motion of the pump piston **118** during operation of the hydraulic tool, as well as reduce the space taken up by the transmission end of the hydraulic tool.

[0077] In some embodiments of the axial pump assembly **100**, components of the axial pump assembly **100** could be configured to reverse the relationship between the motion of the ball elements **108** and the motion of the reciprocating block **102**. In particular, the axial pump assembly **100** could be configured so that movement (i.e., retraction) of the ball elements **108** radially inward extends the reciprocating block **102** and movement of the ball elements **108** radially outward retracts the reciprocating block **102**. To facilitate this, the cam feature of the axial pump assembly **100** could be external to the reciprocating block **102**.

[0078] FIG. **2**A illustrates another embodiment of an axial pump assembly **200** that, similar to the axial pump assembly **100** shown in FIGS. **1**A-E, uses radial movement of ball elements **208** to drive a pump piston **220** (see, for example, FIG. **2**D). In particular, as shown in FIG. **2**A, the axial pump assembly **200** includes a reciprocating block **202**, a sun driver **204**, a pair of bearings **206**, ball elements **208**, a base **210**, and a retaining ring **212**. A compression spring is not shown in FIG. **2**A, since retraction of the axial pump assembly **200** can be achieved without the use of a compression spring.

[0079] The ball elements **208** and the base **210** can take the same or similar forms to the ball elements **108** and the base **110** of the axial pump assembly **100** of FIG. **1**A, respectively. Although the ball elements **208** are shown to include four ball elements **208**, more or less ball elements **208** are possible as well. For example, two ball elements **208** can be used.

[0080] The reciprocating block **202** includes four ramped radial channels **214**, **216** that extend radially outward from an inner circumferential surface **213** of the reciprocating block **202**. Each channel can take the form of a through-hole or a blind hole. Within examples, two of the ramped radial channels **214**—namely, a first pair of ramped radial channels **214** that are positioned radially opposite each other—can be ramped downward (i.e., toward the base **210**, rather than toward a top surface of the reciprocating block **202**), whereas the other two of the ramped radial channels **216**—namely, a second pair of ramped radial channels **216** that are positioned radially opposite each other—can be ramped upward (i.e., toward a top surface of the reciprocating block **202**). In some example embodiments where only two ball elements **208** are used, the reciprocating block **202** might include two ramped radial channels **214** that are positioned opposite each other, each of which might be ramped downward.

[0081] The sun driver **204** is a partially cylindrical-shaped element that functions as a rotational input and can be operatively coupled (e.g., pressed) to a shaft **224** (see, for example, FIG. **2**D) of a motor of the hydraulic tool through a bottom of the base **210**. The sun driver **204** can be coupled directly to the shaft **224** or by way of a gearbox. Further, the sun driver **204** can include a cam groove **218** (i.e., a race or track) in which the ball elements **208** roll. As such, the sun driver **204** can act as a cam. In some examples, the cam groove **218** can be sinusoidal-shaped or shaped in some other manner that coordinates the timing of the movement of the ball elements **208**—namely, so that two of the ball elements **208** that are positioned radially opposite each other move radially outward at substantially the same time as the other two of the ball elements **208** that are positioned radially opposite each other retract radially inward. In alternative embodiments, other groove designs and ramping arrangements for the radial channels are possible as well to achieve the same desired reciprocating movement up and down. The sun driver **204** and its cam groove **218** drive movement of the ball elements **208**, but a geared driver and planetary elements are not used for speed reduction. Thus, speed reduction mechanisms that are external to the axial pump assembly **200** might be required.

[0082] The pair of bearings **206** can be configured to support cam forces. More or less bearings **206** could be used for the same purpose in alternative embodiments. The retaining ring **212** can be configured to hold the pair of bearings **206** axially within the base **210**.

[0083] In operation, the motor rotates the sun driver **204**, pushing two of the ball elements **208** (i.e., two radially opposing ball elements) radially outward into the first pair of ramped radial channels **214** of the reciprocating block **202** and against the ramped surfaces within the channels. This pushes the reciprocating block **202** upwards in a direction substantially parallel to the common axis **226** and away from a peripheral flange **215** of the base **210**. At substantially the same time as two of the ball elements **208** are being pushed radially outward as part of this motion, the other two of the ball elements **208** (i.e., the other two radially opposing ball elements) retract radially inward through the second pair of ramped radial channels **216** of the reciprocating block **202** and toward the sun driver **204**. This motion can thus push the pump piston **220** upward. Following this motion, the two ball elements **208** that were pushed radially outward then retract inward and, at substantially the same time, the two ball elements **208** that were retracted radially inward are then pushed radially outward, bringing the reciprocating block **202** downwards.

[0084] FIG. **2**B is a corner-sectioned view of the axial pump assembly of FIG. **2**A in a retracted position in which the reciprocating block **202** is in a downward position. FIG. **2**C is a corner-sectioned view of the axial pump assembly of FIG. **2**A in an extended position in which the reciprocating block **202** is in an upward position.

[0085] FIG. **2**D is a cross-sectional side view of the axial pump assembly **200** where the axial pump assembly **200** is operatively coupled to a pump piston **220** and a gearbox **222**. FIG. **2**D also depicts a motor shaft **224** that is operatively coupled to the axial pump assembly **200** (i.e., to the sun driver **204**) by way of the gearbox **222**. The gearbox **222** can also be coupled to the base **210** of the axial pump assembly **200**. Further, FIG. **2**D depicts the axis **226** about which the axial pump assembly **200**, the pump piston **220**, and the motor shaft **224** are arranged.

[0086] An advantage of the axial pump assembly **200** is that it uses one set of cam follower elements (i.e., ball elements **208** of FIG. **2**A) to drive motion that is both perpendicular to the axis of the motor shaft **224** (i.e., axis **226**)—namely, the radial movement of the ball elements **208**—and also to drive reciprocating motion that is in line with axis **226** (i.e., motion of the reciprocating block **202** of FIG. **2**A and the pump piston **220** of FIG. **2**D). Another advantage of the axial pump assembly **200** is that the cam groove **218** of the sun driver **204** enables synchronization of the perpendicular and reciprocating motions within a single compact system. Further, another advantage of the axial pump assembly **200** is that the arrangement of the axial pump assembly **200** enables the motor shaft **224** to be coaxial to the line of action of the pump piston **220**, which can help provide stable motion of the pump piston **220** during operation of the hydraulic tool, as well as reduce the space taken up by the transmission end of the hydraulic tool. Yet another advantage of the axial pump assembly **200** is that it has automatic retraction without the need for a compressions spring.

[0087] In some embodiments of the axial pump assembly **200**, components of the axial pump assembly **200** could be configured to reverse the relationship between the motion of the ball elements **208** and the motion of the reciprocating block **202**. In particular, the axial pump assembly **200** could be configured so that movement (i.e., retraction) of the ball elements **208** radially inward extends the reciprocating block **202** and movement of the ball elements **208** radially outward retracts the reciprocating block **202**. To facilitate this, the cam feature of the axial pump assembly **200** could be external to the reciprocating block **202**.

[0088] FIG. **3**A illustrates another embodiment of an axial pump assembly **300** for driving motion of a pump piston **318** (see, for example, FIG. **3**E). The axial pump assembly **300** includes a reciprocating disk **302**, a cycloidal disk **304**, an eccentric bearing **306**, a pair of ball elements **308**, and a base **310**. In some embodiments, a compression spring (not shown) or other component can be used to bias the reciprocating disk **302** in a direction toward the pair of ball elements **308** and also to help hold the axial pump assembly **300** together. Further, in some embodiments, additional components not shown in FIG. **3**A might be included to improve and maintain stability of the pair of ball elements **308**.

[0089] As shown in FIG. **3**B, the reciprocating disk **302** can include a first annular cam groove **312** disposed in a bottom surface **313** of the reciprocating disk **302**. The pair of ball elements **308** can roll in the first annular cam groove **312**. In some examples, the first annular cam groove **312** can be shaped to receive a portion of the pair of ball elements **308**. Further, the first annular cam groove **312** can be tapered so that the deepest portions of the first annular cam groove **312** contact the pair of ball elements **308** at substantially the same time, causing the reciprocating disk **302** to be in a retracted position. Still further, the first annular cam groove **312** can be tapered so that the shallowest portions of the first annular cam groove **312** contact the pair of ball elements **308** at substantially the same time, causing the reciprocating disk **302** to be in an extended position. The retracted position is shown in the cross-sectional view of the axial pump assembly **300** of FIG. **3**C. The extended position is shown in the cross-sectional view of the axial pump assembly **300** of FIG. **3**D.

[0090] Referring back to FIG. **3**A, the cycloidal disk **304** functions as a rotational input and can be operatively coupled to a shaft **320** (see, for example, FIG. **3**E) of the motor of the hydraulic tool through a bottom of the base **310**. For example, the cycloidal disk **304** can be coupled to the shaft **320** by way of the shaft **320** being pressed to the eccentric bearing **306**. Additionally, the cycloidal disk **304** can include a pair of through-holes **315** configured to maintain the pair of ball elements **308** in the first annular cam groove **312**, as well as in the second annular cam groove **314** of the base **310**, and also to rotationally push the pair of ball elements **308** during operation. Further, the cycloidal disk **304** can have a geared periphery **317** for meshing with base pins **316** of the base **310**. As so arranged, the cycloidal disk **304** can provide speed reduction. The cycloidal disk **304** can also include a through-hole **319** configured to encircle the eccentric bearing **306**. The eccentric bearing **306** can be configured to generate rotational eccentricity that drives cycloidal transmission. The pair of ball elements **308** can be configured to act as cam followers that transmit axial forces between the reciprocating disk **302** and the base **310**.

[0091] The base **310** can be configured to act as housing for other components of the axial pump assembly **300** and to provide a reaction force to drive the cycloidal disk **304**. As noted above, the base **310** can include the second annular cam groove **314** which, unlike the first annular cam groove **312** might have a uniform depth.

[0092] In operation, rotation of the shaft rotates the cycloidal disk **304**, thus rotationally pushing the pair of ball elements **308**. The movement of the pair of ball elements **308** in the first annular cam groove **312** thus causes the reciprocating disk **302** to move up and down between the retracted position and the extended position.

[0093] FIG. **3**E is a cross-sectional side view of the axial pump assembly **300** where the axial pump assembly **300** is operatively coupled to the pump piston **318** and the motor shaft **320**. As mentioned above, the cycloidal disk **304** of the axial pump assembly **300** can be operatively coupled to the motor shaft **320**. Although a compression spring is not depicted in FIG. **3**E, the block representing the pump piston **318** can represent both the compression spring and the pump piston **318**. Further, FIG. **3**E depicts an axis **322** about which the axial pump assembly **300**, the pump piston **318**, and the motor shaft **320** are arranged.

[0094] An advantage of the axial pump assembly **300** is that it combines mechanisms for reciprocation and speed reduction into a single compact system requiring less parts for operation than in some existing systems. This is accomplished by using cam followers (i.e., ball elements **308** of FIG. **3**A) that interact with a cam of a reciprocating element (i.e., the first annular cam groove

312 of reciprocating disk **302**). Further, another advantage of the axial pump assembly **300** is that the arrangement of the axial pump assembly **300** enables the motor shaft **320** to be coaxial to the line of action of the pump piston **318**, which can help reduce the space taken up by the transmission end of the hydraulic tool.

[0095] FIG. **4**A illustrates another embodiment of an axial pump assembly **400** for driving motion of a pump piston **424** (see, for example, FIG. **4**E). In particular, the axial pump assembly **400** uses a tangential cam to create axial motion. The axial pump assembly **400** includes a reciprocating disk **402**, a cycloidal disk **404**, an eccentric bushing **406**, a pair of cam roller bushings **408**, a base **410**, four second-stage bushings **412**, a second-stage disk **414**, and a bearing **416**. In some embodiments, a compression spring (not shown in FIG. **4**A) or other component can be used to bias the reciprocating disk **402** in a direction toward the pair of cam roller bushings **408** and also to help hold the axial pump assembly **400** together.

[0096] As shown in FIG. **4**B, the reciprocating disk **402** can include a cam groove **418** disposed on or in an inner circumferential surface **413** of the reciprocating disk **402**. By way of the cam groove **418**, the reciprocating disk **402** interacts axially with the pair of cam roller bushings **408** to create reciprocating motion of the reciprocating disk **402** between a retracted position and an extended position. The retracted position is shown in the cross-sectional view of the axial pump assembly **400** of FIG. **4**C. The extended position is shown in the cross-sectional view of the axial pump assembly **400** of FIG. **4**D.

[0097] Referring back to FIG. **4**A, the cycloidal disk **404** functions as a rotational input and can be operatively coupled to a shaft **426** (see, for example, FIG. **4**E) of the motor (not shown) of the hydraulic tool through a bottom of the base **410**. For example, the cycloidal disk **404** can be coupled to the shaft **426** by way of the shaft **426** being pressed to the eccentric bushing **406**. The cycloidal disk **404** can be positioned between the reciprocating disk **402** and the second-stage disk **414**. Additionally, the cycloidal disk **404** can include five through-holes **415**, four of which are configured to receive the four second-stage bushings **412** and four disk pins **420** protruding from the second-stage disk **414**, and one of which is configured for receiving the eccentric bushing **406**. The eccentric bushing **406** can be configured to generate rotational eccentricity that drives cycloidal transmission. Further, the cycloidal disk **404** can have a geared periphery for meshing with base pins **422** of the base **410** and providing speed reduction.

[0098] As so arranged, the cycloidal disk **404**, in operation, can convert eccentric motion to rotational motion—namely, rotational motion that drives rotation of the second-stage disk **414**. Each cam roller bushing of the pair of cam roller bushings **408** can include a through-hole, a blind hole, or other manner of coupling the cam roller bushing **408** to one of the four disk pins **420**. Thus, in operation, the rotational motion of the second-stage disk **414** is translated to the pair of cam roller bushings **408**, which in turn interact axially with the cam groove **418** of the reciprocating disk **402**, causing the reciprocating disk **402** to move up and down between the retracted position and the extended position.

[0099] Furthermore, the four second-stage bushings **412** can be slid around or otherwise coupled to the four disk pins **420** and are configured to reduce frictional resistance between the four disk pins **420** and the cycloidal disk **404**. Similarly, the bearing **416** can encircle the second-stage disk **414** and is configured to reduce frictional resistance between the base **410** and the second-stage disk **414**. The base **410** can be configured to act as housing for other components of the axial pump assembly **400** and to provide a reaction force to drive the cycloidal disk **404**.

[0100] FIG. **4**E is a cross-sectional side view of the axial pump assembly **400** where the axial pump assembly **400** is operatively coupled to the pump piston **424** and the motor shaft **426**. As mentioned above, the cycloidal disk **404** of the axial pump assembly **400** can be operatively coupled to the motor shaft **426**. Although a compression spring is not depicted in FIG. **4**E, the block representing the pump piston **424** can represent both the compression spring and the pump piston **424**. Further, FIG. **4**E depicts an axis **428** about which the axial pump assembly **400**, the pump piston **424**, and the motor shaft **426** are arranged.

[0101] An advantage of the axial pump assembly **400** is that it combines mechanisms for reciprocation and speed reduction into a single system. This is accomplished by combining a cam system with a cycloidal reducer. Further, another advantage of the axial pump assembly **400** is that the arrangement of the axial pump assembly **400** enables the motor shaft **426** to be coaxial to the line of action of the pump piston **424**, which can help reduce the space taken up by the transmission end of the hydraulic tool and can also help maintain stable motion.

[0102] In alternative embodiments, a planetary gear system could be incorporated with the axial pump assembly **400**. In other alternative embodiments, more or less disk pins, base pins, and second-stage bushings could be used. For example, in one embodiment, no second-stage bushings might be used.

[0103] FIG. **5**A illustrates an exploded view of another embodiment of an axial pump assembly **500** for driving motion of a pump piston **524** (See, for example FIG. **5**D). In particular, the axial pump assembly **500** uses an axial cam to create motion. The axial pump assembly **500** includes a reciprocating plate **502**, a cycloidal disk **504**, an eccentric bushing **506**, a pair of cam follower bushings **508**, a base **510**, a ring element **512**, five second-stage bushings **514**, and a bearing **516**. In some embodiments, a compression spring (not shown in FIG. **5**A) or other component can be used to bias the reciprocating plate **502** in a retracted position and also to help hold the axial pump assembly **500** together. The reciprocating plate **502** can include two opposing side members around which the pair of cam follower bushings **508** are positioned.

[0104] The cycloidal disk **504** functions as a rotational input and can be operatively coupled to a shaft **526** (see, for example, FIG. **5**D) of the motor (not shown) of the hydraulic tool through a bottom of the base **510**. For example, the cycloidal disk **504** can be coupled to the shaft by way of the shaft being pressed to the eccentric bushing **506**. The cycloidal disk **504** can be mounted to the base **510** by way of five base pins **518** protruding from the base **510** and can be mounted so that the cycloidal disk **504** is positioned between the reciprocating plate **502** and the bottom of the base **510**. Additionally, the cycloidal disk **504** can include six through-holes **515**, five of which are configured to receive the five second-stage bushings **514** and the five base pins **518**, and one of which is configured for receiving the eccentric bushing **506**. The eccentric bushing **506** can be configured to generate rotational eccentricity that drives cycloidal transmission. Further, the cycloidal disk **504** can have a geared periphery **517** for meshing with outer pins **520** of the ring element **512**.

[0105] In addition, the ring element **512** can include an annular cam track **522** protruding from the ring element **512** and along which the pair of cam follower bushings **508** roll to produce reciprocating motion. The annular cam track **522** can be tapered such that the deepest portions of the annular cam track **522** contact the pair of cam follower bushings **508** at substantially the same time, thereby causing the reciprocating plate **502** to be in a retracted position. Further, the annular cam track **522** can be tapered such that the shallowest portions of the annular cam track **522** contact the pair of cam follower bushings **508** at substantially the same time, causing the reciprocating plate **502** to be in an extended position. The retracted position is shown in the perspective view of the axial pump assembly **500** of FIG. **5**B. The extended position is shown in the perspective view of the axial pump assembly **500** of FIG. **5**C.

[0106] Through the meshing of the outer pins **520** with the geared periphery of the cycloidal disk **504**, the ring element **512** receives rotational motion from the cycloidal disk **504**. This rotational motion is then translated to reciprocating motion of the reciprocating plate **502** between the retracted position and the extended position by way of the pair of cam follower bushings **508** rolling on the annular cam track **522**.

[0107] Furthermore, the five second-stage bushings **514** can be slid around or otherwise coupled to the five base pins **518** and are configured to reduce frictional resistance between the five base pins **518** and the cycloidal disk **504**. Similarly, the bearing **516** can encircle the ring element **512** and be positioned between the ring element **512** and the side wall of the base **510**. The bearing **516** is configured to reduce frictional resistance between the base **510** and the ring element **512**. For simplicity, the bearing **516** is not shown in FIGS. **5**B and **5**C. Moreover, the base **510** can be configured to act as housing for other components of the axial pump assembly **500** and to provide a reaction force to drive the cycloidal disk **504** and the ring element **512**.

[0108] As so arranged, the cycloidal disk **504**, in operation, can convert eccentric motion to rotational motion—namely, motion that drives rotation of the ring element **512**. In particular, rotation of the motor shaft causes the cycloidal disk **504** to oscillate eccentrically, back and forth in a circular motion. Reaction forces between the cycloidal disk **504** and the five second-stage bushings **514** (or, in an embodiment where no bushings a present, then between the cycloidal disk **504** and the five base pins **518**) cause the geared periphery of the cycloidal disk **504** to push on the outer pins **520**, driving rotation of the ring element **512** and, in turn, reciprocating motion of the reciprocating plate **502**.

[0109] FIG. **5**D is a cross-sectional side view of the axial pump assembly **500** where the axial pump assembly **500** is operatively coupled to the pump piston **524** and the motor shaft **526**. As mentioned above, the cycloidal disk **504** of the axial pump assembly **500** can be operatively coupled to the motor shaft **526**. Although a compression spring is not depicted in FIG. **5**D, the block representing the pump piston **524** can represent both the compression spring and the pump piston **524**. Further, FIG. **5**D depicts an axis **528** about which the axial pump assembly **500**, the pump piston **524**, and the motor shaft **526** are arranged.

[0110] An advantage of the axial pump assembly **500** is that it combines mechanisms for reciprocation and speed reduction into a single system. This is accomplished by combining a cam system with a cycloidal reducer. Further, another advantage of the axial pump assembly **500** is that the arrangement of the axial pump assembly **500** enables the motor shaft **526** to be coaxial to the line of action of the pump piston **524**, which can help reduce the space taken up by the transmission end of the hydraulic tool and can also help maintain stable motion. The axial pump assembly **500** also differs from some existing arrangements in that the cycloidal disk **504** oscillates eccentrically instead of rotating.

[0111] In alternative embodiments, a planetary gear system could be incorporated with the axial pump assembly **500**. In other alternative embodiments, more or less disk pins, base pins, and second-stage bushings could be used. For example, in one embodiment, no second-stage bushings might be used.

[0112] FIGS. **6**A-**6**C and **7**A-**7**C relate to another form that an axial pump assembly might take-particularly, where reciprocating motion is generated by a pump piston that is transverse to other components of the axial pump assembly and perpendicular to an axis about which a shaft of the motor (and thus, the cycloidal disk) rotates. Similar to the embodiments described above, each of the example axial pump assemblies shown in FIGS. **6**A-**6**C and **7**A-**7**C are compact and combine speed reduction and reciprocating motion in a single mechanism.

[0113] FIG. **6**A illustrates an exploded view of another embodiment of an axial pump assembly **600** for driving motion of a pump piston **602**. In addition to the pump piston **602**, the axial pump assembly **600** includes a cycloidal disk **604**, an eccentric bearing **606**, a pair of cam follower bearings **608**, a base **610**, a second-stage cam **612** operatively coupled to the cycloidal disk **604**, five second-stage bushings **614**, and a load supporting bearing **616**. Also shown is a manifold **618**, which can house hydraulic components (e.g., check valves) and through which hydraulic fluid can be pumped. Although FIG. **6**A shows the manifold **618**, the manifold **618** might be considered to not be a component of the axial pump assembly **600** in some embodiments.

[0114] The pump piston **602** is bi-diametral and transverse, comprising a first section **603** having a first diameter and a second section **605** having a second diameter that is larger than the first diameter. The two diameters enable hydraulic fluid to be pumped through the manifold **618**. The pump piston **602** is arranged partially within the manifold **618**.

[0115] The cycloidal disk **604** functions as a rotational input and can be operatively coupled to a shaft **624** (see, for example, FIG. **6**D) of the motor (not shown) of the hydraulic tool through a bottom of the base **610**. For example, the cycloidal disk **604** can be coupled to the shaft by way of the shaft being pressed to the eccentric bearing **606**. The cycloidal disk **604** can be positioned between the second-stage cam **612** and the bottom of the base **610**. Additionally, the cycloidal disk **604** can include six through-holes **615**, five of which are configured to receive the five second-stage bushings **614** and five cam pins **620** protruding from the bottom of the second-stage cam **612**, and one of which is configured for receiving the eccentric bearing **606**. The eccentric bearing **606** can be configured to generate rotational eccentricity that drives cycloidal transmission. Further, the cycloidal disk **604** can have a geared periphery **617** for meshing with base pins **622** of the base **610**. As so arranged, the cycloidal disk **604**, in operation, provides speed reduction and can convert eccentric motion to rotational motion—namely, rotational motion that drives rotation of the second-stage cam **612**.
[0116] The pair of cam follower bearings **608** are coupled to the ends of the pump piston **602**. Rotational motion of the second-stage cam **612** pushes the pair of cam follower bearings **608**, which moves the pump piston **602** back and forth between a retracted position and an extended position. The retracted position is shown in the perspective view of the axial pump assembly **600** of FIG. **6**B. The extended position is shown in the perspective view of the axial pump assembly **600** of FIG. **6**C. In FIGS. **6**B and **6**C, the manifold **618** is sectioned in order to show the position of the pump piston **602**.
[0117] Furthermore, the five second-stage bushings **614** can be slid around or otherwise coupled to the five cam pins **620** and are configured to transmit rotational force from the cycloidal disk **604** to the second-stage cam **612**. In addition, the load supporting bearing **616** can be slid around or otherwise coupled to the manifold **618** and is configured to support loads from the second-stage cam **612**.
[0118] FIG. **6**D is a cross-sectional side view of the axial pump assembly **600** where the axial pump assembly **600** is operatively coupled to the motor shaft **624**. As mentioned above, the cycloidal disk **604** of the axial pump assembly **600** can be operatively coupled to the motor shaft **624**. Further, FIG. **6**D depicts a first axis **626** about which the motor shaft **624** rotates (i.e., the longitudinal axis of the motor shaft **624**) and about which the cycloidal disk **604** is arranged. FIG. **6**D also depicts a second axis **628** that is substantially perpendicular to the first axis **626** and along which the pump piston **602** moves (i.e., the longitudinal axis of the pump piston **602**). In some embodiments, the second axis **628** can be centered on the first axis **626** (e.g., so that the longitudinal axis of the motor shaft **624** and the longitudinal axis of the pump piston **602** substantially intersect).
[0119] An advantage of the axial pump assembly **600** is that it combines mechanisms for reciprocation and speed reduction into a compact system. This is accomplished by combining a cam system with a cycloidal disk (i.e., cycloidal disk **604** of FIG. **6**A) that also acts as a speed reducer. Further, another advantage of the axial pump assembly **600** is that a return spring is not necessary for reciprocating motion, since the points at which the pair of cam followers **608** of FIG. **6**A contact the second-stage cam **612** are offset from the second axis **628**. Another advantage of the axial pump assembly **600** is that the cam feature being separate from the cycloidal element allows for smooth interaction but might require a central load supporting bearing. In other embodiments, more or less second-stage bushings could be used. For example, in one embodiment, no second-stage bushings might be used.
[0120] FIG. **7**A illustrates an exploded view of another embodiment of an axial pump assembly **700** for driving motion of a pump piston **702**. In addition to the pump piston **702**, the axial pump assembly **700** includes a cycloidal disk **704**, an eccentric bearing **706**, a pair of cam follower bearings **708**, and a base **710**. Also shown is a manifold **712**, which can house hydraulic components (e.g., check valves) and through which hydraulic fluid can be pumped. Although FIG.

7A shows the manifold **712**, the manifold **712** might be considered to not be a component of the axial pump assembly **700** in some embodiments.

[0121] The axial pump assembly **700** of FIG. **7**A operates similarly to the axial pump assembly **600** of FIG. **6**A, except the cycloidal disk **704** is integrated with a second-stage cam (e.g., second stage cam **612** of FIG. **6**A). In other words, as opposed to having two separate components—a cycloidal disk and a second-stage cam, the cycloidal disk **704** of FIG. **7**A is a single component including a second-stage cam portion **714** and a geared portion **716**. The eccentric bearing **706**, the pair of cam follower bearings **708**, and the base **710** can each be configured the same as their corresponding component described above with respect to FIG. **6**A.

[0122] In operation, rotational motion of the second-stage cam portion **714** of the rotating cycloidal disk **704** pushes the pair of cam follower bearings **708**, which moves the pump piston **702** back and forth between a retracted position and an extended position. The retracted position is shown in the perspective view of the axial pump assembly **700** of FIG. **7**B. The extended position is shown in the perspective view of the axial pump assembly **700** of FIG. **7**C. In FIGS. **7**B and **7**C, the manifold **712** is sectioned in order to show the position of the pump piston **702**.

[0123] FIG. **7**D is a cross-sectional side view of the axial pump assembly **700** where the axial pump assembly **700** is operatively coupled to a motor shaft **718**. As mentioned above, the cycloidal disk **704** of the axial pump assembly **700** can be operatively coupled to the motor shaft **718**. Further, FIG. **7**D depicts a first axis **720** about which the motor shaft **718** rotates (i.e., the longitudinal axis of the motor shaft **718**) and about which the cycloidal disk **704** is arranged. FIG. **7**D also depicts a second axis **722** that is substantially perpendicular to the first axis **720** and along which the pump piston **702** moves (i.e., the longitudinal axis of the pump piston **702**). In some embodiments, the second axis **722** can be centered on the first axis **720** (e.g., so that the longitudinal axis of the motor shaft **718** and the longitudinal axis of the pump piston **702** substantially intersect).

[0124] An advantage of the axial pump assembly **700** is that it combines mechanisms for reciprocation and speed reduction into a compact system requiring less parts for operation than in some existing systems. This is accomplished by combining a cam system with a cycloidal disk (i.e., cycloidal disk **704** of FIG. **7**A) that also acts as a speed reducer. Further, another advantage of the axial pump assembly **700** is that a return spring is not necessary for reciprocating motion, since the points at which the pair of cam followers **708** of FIG. **7**A contact the second-stage cam portion **714** are offset from the second axis **722**. Another advantage of the axial pump assembly **700** is that the cam feature is merged with the cycloidal element, thus eliminating the need for a central load supporting bearing.

[0125] By the term “substantially” or “about” used herein, it is meant that the recited characteristic, parameter, value, or geometric planarity need not be achieved exactly, but that deviations or variations, including for example, tolerances, measurement error, measurement accuracy limitations and other factors known to skill in the art, may occur in amounts that do not preclude the effect the characteristic was intended to provide.

[0126] The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

Claims

1. An axial pump assembly for a hydraulic tool, the axial pump assembly comprising: a cycloidal disk rotatable about an axis and having an eccentric opening configured to receive a rotational input; a ring defining a cam track, the ring engaged with the cycloidal disk so that rotation of the cycloidal disk causes corresponding rotation of the ring about the axis; and a plate including a follower that engages with cam track so that rotation of the cam track causes corresponding reciprocating motion of the plate along the axis.

2. The axial pump assembly of claim 1, wherein the cycloidal disk defines a geared periphery and the ring includes a plurality of pins that engage with the geared periphery to transmit rotation of the cycloidal disk to the ring.

3. The axial pump assembly of claim 1, wherein the eccentric opening is defined by a bushing that is received in a central opening defined in the cycloidal disk.

4. The axial pump assembly of claim 1 wherein a plurality of pins extends between the cycloidal disk and the plate.

5. The axial pump assembly of claim 4, wherein the ring rotates relative to each of the cycloidal disk and the plate.

6. The axial pump assembly of claim 4, wherein the plurality of pins extends through the ring.

7. The axial pump assembly of claim 6, wherein the cycloidal disk includes a plurality of holes arranged around the eccentric opening to receive the plurality of pins.

8. The axial pump assembly of claim 7, further comprising a plurality bushings that are positioned in the plurality of holes and receive the plurality of pins.

9. The axial pump assembly of claim 4 further comprising a base that includes the plurality of pins.

10. The axial pump assembly of claim 9, wherein the base defines a recess that receives each of the cycloidal disk, the ring, and the plate.

11. The axial pump assembly of claim 10 further comprising a bearing that is positioned between the ring and a sidewall of the base.

12. An axial pump assembly for a hydraulic tool, the axial pump assembly comprising: a rotational input extending along and rotatable about an axis; a cycloidal disk having an eccentric opening that receives the rotational input so that rotation of the rotational input causes rotation of the cycloidal disk about the axis, the cycloidal disk further defining a plurality of holes arranged around the eccentric opening; a cam rotated by the cycloidal disk about the axis; a plate that engages with the cam so that rotation of the cam causes corresponding reciprocating motion of the plate along the axis; and a base including a first plurality of pins that extend along the axis and through the plurality of holes in the cycloidal disk to the plate so that the plate is rotationally fixed to the base.

13. The axial pump assembly of claim 12 further comprising a bearing positioned between the base and the cam.

14. The axial pump assembly of claim 12, wherein the cam rotates at a reduced speed relative to the rotational input.

15. The axial pump assembly of claim 14, wherein the cycloidal disk defines a geared periphery that engages with a second plurality of pins extending away from the cam.

16. The axial pump assembly of claim 12, wherein the plate is engaged with the cam via follower bushings.

17. The axial pump assembly of claim 12, wherein the rotational input is a shaft of a motor that extends through the base to the eccentric opening.

18. The axial pump assembly of claim 12, wherein the eccentric opening is defined in an eccentric bushing that is received in a central opening of the cycloidal disk, and wherein a plurality bushings are positioned in the plurality of holes to be between the first plurality of pins and the cycloidal disk.

19. A method of operating an axial pump assembly, the method comprising: driving a cycloidal disk via a rotational input that is received in an eccentric opening of the cycloidal disk, the rotational input defining an axis of rotation; rotating a cam about the axis of rotation with the cycloidal disk; and reciprocating a plate that is engaged with the cam so that rotation of the cam causes corresponding reciprocating motion of the plate along the axis of rotation.

20. The method of claim 19, wherein the cam rotates at a reduced speed relative to the rotational input.