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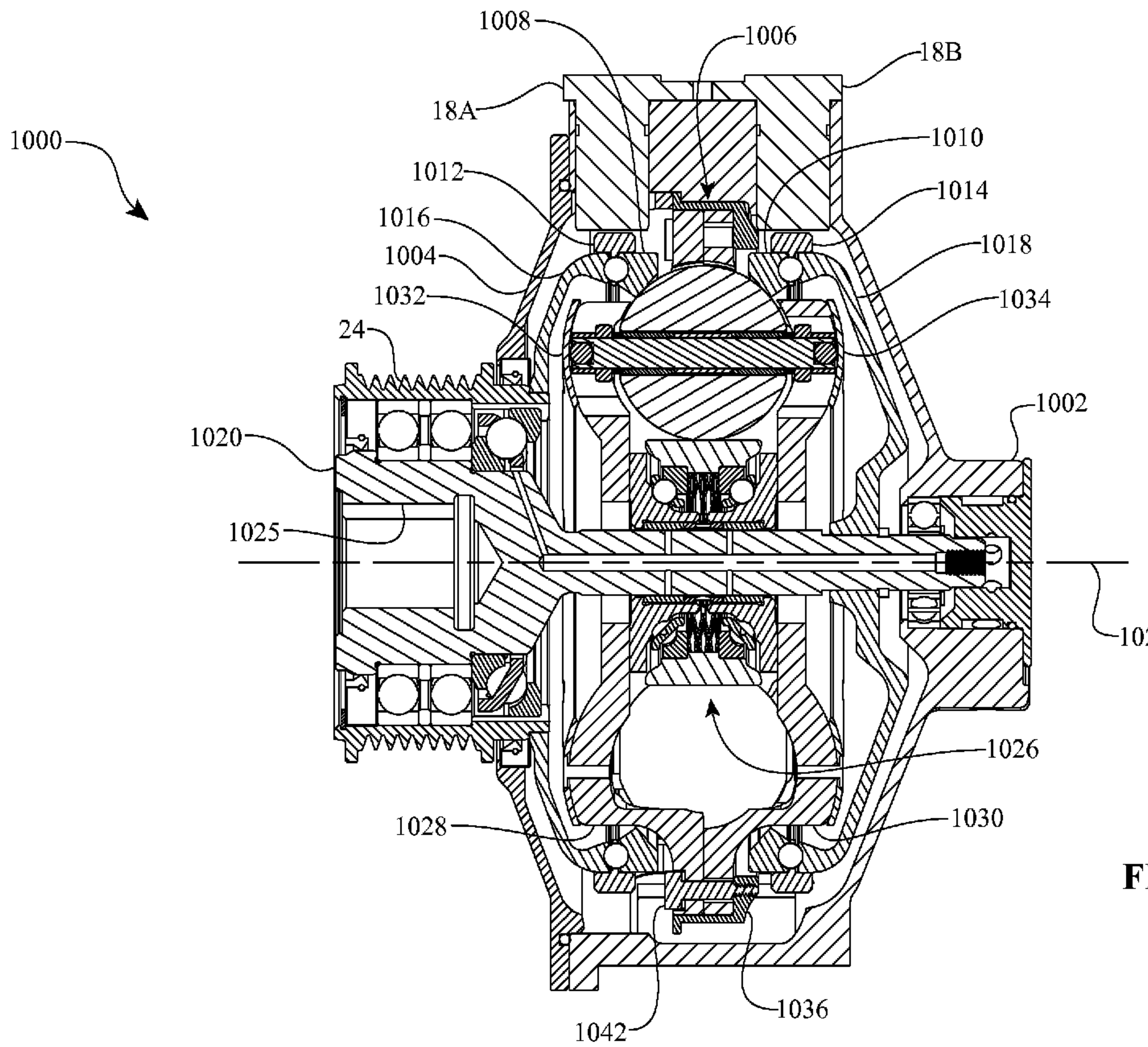

FIG. 15

(57) Abrégé/Abstract:
Continuously variable transmission (1000) with a first (1028) and a second (1030) carrier member, which are axially coupled by a carrier retaining ring (1036) and which are relatively rotational to each other. The transmission ratio is changed by tilting the axles of the traction planets (spheres), which is caused by a relative rotation between the first and second carrier members.

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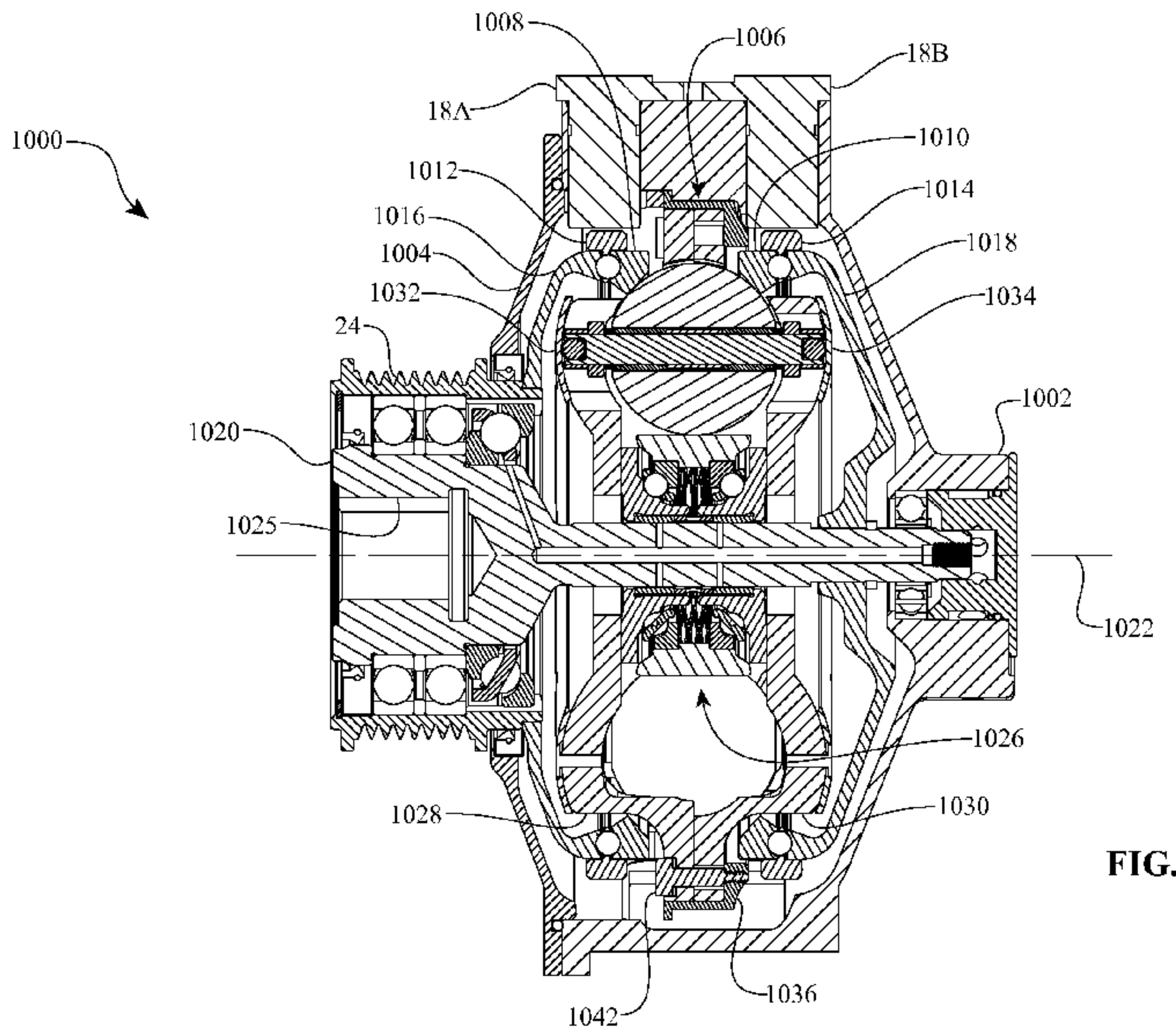

FIG. 15

(57) **Abstract**: Continuously variable transmission (1000) with a first (1028) and a second (1030) carrier member, which are axially coupled by a carrier retaining ring (1036) and which are relatively rotational to each other. The transmission ratio is changed by tilting the axles of the traction planets (spheres), which is caused by a relative rotation between the first and second carrier members.

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CONTINUOUSLY VARIABLE TRANSMISSION

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The field of the invention relates generally to mechanical and/or electro-mechanical power modulation devices and methods, and more particularly to continuously and/or infinitely variable, planetary power modulating devices and methods for modulating power flow in a power train or drive, such as power flow from a prime mover to one or more auxiliary or driven devices.

Description of the Related Art

[0002] In certain systems, a single power source drives multiple devices. The power source typically has a narrow operating speed range at which the performance of the power source is optimum. It is preferred to operate the power source within its performance optimizing operating speed range. A driven device typically also has a narrow operating speed range at which the performance of the driven device is optimum. It is also preferred to operate the driven device within its performance optimizing operating speed range. A coupling is usually employed to transfer power from the power source to the driven device. Where a direct, non-modulating coupling couples the power source to the driven device, the driven device operates at a speed proportional to that of the power source. However, it is often the case that the optimum operating speed of the driven device is not directly proportional to the optimum operating speed of the power source. Therefore, it is preferred to incorporate into the system a coupling adapted to modulate between the speed of the power source and the speed of the driven device.

[0003] Couplings between the power source and the driven devices can be selected such that the input speed from the power source is reduced or increased at the output of a given coupling. However, in frequently implemented systems, typical known power train configurations and/or coupling arrangements allow at best for a constant ratio between the input speed from the power source and the speed of power transfer to the driven device. One such system is the so-called front end accessory drive (FEAD) system employed in many automotive applications. In a typical FEAD system, the prime mover (usually an internal combustion engine) provides the power to run one or more accessories, such as a cooling fan, water pump, oil pump, power steering pump, alternator, etc. During operation of the automobile, the accessories are forced to operate at speeds that have a fixed relationship to the speed of the prime mover. Hence, for example, as the speed of the engine increases from 800 revolutions per minute (rpm) at idle to 2,500 rpm at cruising speed, the speed of each accessory driven by the engine increases proportionally to the increase in engine speed, such that some accessories may be operating at varying speeds ranging between 1,600 rpm to 8,000 rpm. The result of such system configuration is that often any given accessory does not operate within its maximum efficiency speed range. Consequently, inefficiencies arise from wasted energy during operation and oversizing of the accessories to handle the speed and/or torque ranges.

[0004] Thus, there exists a continuing need for devices and methods to modulate power transfer between a prime mover and driven devices. In some systems, it would be beneficial to regulate the speed and/or torque transfer from an electric motor and/or internal combustion engine to one or more driven devices that operate at varying efficiency optimizing speeds. In some current automotive applications, there is a need for a power modulating device to govern the front end accessory drive within existing packaging limits. The inventive embodiments of power modulating devices and/or drivetrains described below address one or more of these needs.

SUMMARY OF THE INVENTION

[0005] The systems and methods herein described have several features, no single one of which is solely responsible for its desirable attributes. Without limiting the scope as expressed by the claims that follow, its more prominent features will now be discussed briefly. After considering this discussion, and particularly after reading the section entitled "Detailed Description of Certain Inventive Embodiments" one will understand how the features of the system and methods provide several advantages over traditional systems and methods.

[0006] One aspect of the invention relates to a continuously variable accessory drive (CVAD) having an accessory device and a continuously variable transmission (CVT) coupled to the accessory device. The continuously variable transmission has a group of traction planets. Each traction planet can be adapted to rotate about a tiltable axis. The CVAD also includes a skew actuator operably coupled to the CVT. The skew actuator can be adapted to apply a skew condition to the CVT to tilt the axes of the traction planets.

[0007] Another aspect of the invention concerns a continuously variable accessory drive (CVAD) having a group of traction planets arranged angularly about a longitudinal axis of the CVAD. The CVAD can include a group of planet axles. Each planet axle is operably coupled to each traction planet. Each planet axle defines a tiltable axis of rotation for each traction planet. Each planet axle can be configured for angular displacement in a plane perpendicular to the longitudinal axis. Each planet axle can be configured for angular displacement in a plane parallel to the longitudinal axis. In one embodiment, the CVAD includes a first carrier member that is operably coupled to a first end of each planet axle. The first carrier member can be mounted about the longitudinal axis. The CVAD includes a second carrier member that is operably coupled to a second end of each planet axle. The second carrier member can be mounted about the longitudinal axis. The first and second carrier members are configured to rotate relative to each other about the longitudinal axis.

[0008] Yet another aspect of the invention concerns a continuously variable accessory drive (CVAD) having a rotatable input coaxial with a longitudinal axis of the CVAD. The CVAD has a variator coaxial with the longitudinal axis and coupled to the rotatable input. The variator has a rotatable output. The CVAD has a planetary gear assembly coupled to the rotatable output. The planetary gear assembly is configured to power an accessory device. In one embodiment, the variator includes a group of traction planets arranged angularly about the main shaft. The variator can include a first carrier member that is operably coupled to each of the traction planets. The variator can also include a second carrier member that is operably coupled to each of the traction planets. The second carrier member is configured to rotate relative to the first carrier member to thereby apply a skew condition on each of the planet axles.

[0009] One aspect of the invention concerns a continuously variable accessory drive (CVAD) having a group of traction planets arranged angularly about a longitudinal axis of the CVAD. In one embodiment, the CVAD includes a group of planet axles operably coupled to each traction planet. Each planet axle defines a tiltable axis of rotation for each traction planet. Each planet axle can be configured for angular displacement in a plane perpendicular to the longitudinal axis. Each planet axle can be configured for angular displacement in a plane parallel to the longitudinal axis. In one embodiment, the CVAD includes a first carrier member arranged coaxial about the longitudinal axis. The first carrier member can be operably coupled to each traction planet. The first carrier member can have a number of radially offset slots arranged angularly about a center of the first carrier member. Each of the radially offset slots has a linear offset from a centerline of the carrier member. The CVAD can include a second carrier member arranged coaxial about the longitudinal axis. The second carrier member can have a number of radial slots. The radial slots can be arranged angularly about a center of the second carrier member. Each of the radial slots are substantially radially aligned with the center of the second carrier member. The CVAD can also include a skew actuator that is operably coupled to at least one of the first and second carrier members. The actuator can be configured to impart a relative rotation between the first and second carrier members.

[0010] Another aspect of the invention relates to a method of facilitating control of the speed ratio of a continuously variable accessory drive (CVAD). In one embodiment, the method includes the step of providing a group of traction planets. The method includes the step of providing each of the traction planets with a planet axle. Each traction planet can be configured to rotate about a respective planet axle. The method can include the step of providing a first carrier member that is configured to engage a first end of each of the planet axles. The first carrier member can be mounted along a longitudinal axis of the CVAD. The method can include the step of providing a second carrier member that is configured to engage a second end of each of the planet axles. The second carrier member can be mounted coaxially with the first carrier member. The method can also include the step of arranging the first carrier member relative to the second carrier member such that during operation of the CVAD the first carrier member can be rotated relative to the second carrier member about the longitudinal axis.

[0011] Another aspect of the invention concerns a variator having a group of traction planets arranged angularly about a longitudinal axis. In one embodiment, the variator has a first carrier member that is arranged coaxial about the longitudinal axis. The first carrier member can be operably coupled to each traction planet. The first carrier member can have a number of radially offset slots that are arranged angularly about a center of the first carrier member. In one embodiment, each of the radially offset slots has a linear offset from a centerline of the carrier member. The variator can also have a second carrier member that is arranged coaxial about the longitudinal axis. The second carrier member can have a number of radial slots. In one embodiment, the radial slots are arranged angularly about a center of the second carrier member. Each of the radial slots are substantially radially aligned with the center of the second carrier member. The variator can also have a traction sun assembly radially inward of, and in contact with, each traction planet. The traction sun assembly can contact the first and second carrier members. The traction sun assembly is substantially fixed along the longitudinal axis.

[0012] Another aspect of the invention relates to a method of assembling a device for modulating power to an accessory device. The method includes the steps of providing a continuously variable transmission (CVT) having a group of traction planets arranged angularly about a longitudinal axis. In one embodiment, the CVT has a skew-based control system adapted to apply a skew condition to each of the traction planets. The method also includes the step of operably coupling the CVT to the accessory device.

[0013] Yet one more aspect of the invention addresses a variator having a group of traction planets that are arranged angularly about a longitudinal axis. In one embodiment, the variator includes a first carrier member that is arranged coaxial about the longitudinal axis. The first carrier member can be operably coupled to each traction planet. The first carrier member has a number of radially offset slots that are arranged angularly about a center of the first carrier member. Each of the radially offset slots has a linear offset from a centerline of the carrier member. The variator can include a second carrier member that is arranged coaxial about the longitudinal axis. In one embodiment, the second carrier member has a number of radial slots. The radial slots can be arranged angularly about a center of the second carrier member. Each of the radial slots are substantially radially aligned with the center of the second carrier member. The variator can also include a traction sun located radially inward of, and in contact with, each traction planet. The traction sun has an outer periphery provided with a first and a second contact surface. The first and second contact surfaces can be configured to contact each of the traction planets.

[0014] In another aspect, the invention concerns a variator having a group of traction planets that are arranged angularly about a longitudinal axis. In one embodiment, the variator has a planet axle operably coupled to each traction planet. The planet axle can be configured to provide a tiltable axis of rotation for each traction planet. The variator can include a first carrier member that is arranged coaxially about the longitudinal axis. The first carrier member can be operably coupled to a first end of the planet axle. The variator can include a second carrier member that is arranged coaxially about the longitudinal axis. The second carrier member can be operably coupled to a second end of the planet axle. The variator can also include a carrier retaining ring that is coupled to the first and second carrier members. The carrier retaining ring can be substantially non-rotatable about the longitudinal axis. The carrier retaining ring can be configured to axially couple the first and second carrier members. The first carrier member is configured to rotate with respect to the second carrier member to thereby apply a skew condition on each of the planet axles.

[0015] One aspect of the invention relates to a variator having a group of traction planets that are arranged angularly about a longitudinal axis. The variator includes a first carrier member that is coaxial with the longitudinal axis. In one embodiment, the variator includes a second carrier member coaxial with the longitudinal axis. The variator can include a skew driver coupled to the first and second carrier members. The skew driver can be adapted to rotate the first carrier member in a first rotational direction about the longitudinal axis. The skew driver can be adapted to rotate the second carrier member in a second rotational direction about the longitudinal axis. The first rotational direction is substantially opposite to the second rotational direction.

[0016] Another aspect of the invention relates to a method of adjusting a speed ratio of a continuously variable accessory drive (CVAD) having a group of traction planets. Each traction planet has a tiltable axis of rotation. In one embodiment, the CVAD has a carrier member operably coupled to each of the traction planets. The method can include the step of determining a set point for an angular displacement of the carrier member. The set point for the angular displacement of the carrier member is based at least in part on a set point for the speed ratio. The method includes the step of rotating the carrier member to the set point for the angular displacement of the carrier member. Rotating the carrier member induces a skew condition on each tiltable axis of rotation. The carrier member is configured to adjust the skew condition as each tiltable axis of rotation tilts. Rotating the carrier member comprises actuating a skew actuator.

[0017] Yet one more aspect of the invention addresses a method of adjusting a speed ratio of a continuously variable accessory drive (CVAD) having a group of traction planets. Each traction planet has a tiltable axis of rotation. The CVAD has a skew actuator operably coupled to each of the traction planets. In one embodiment, the method includes the step of determining a skew actuator command signal. The skew actuator command signal is based at least in part on a set point for the tilt angle. The method also includes the step of applying the skew actuator command signal to the skew actuator to thereby adjust the skew condition of the traction planets.

[0018] One aspect of the invention concerns a method of adjusting a speed ratio of a continuously variable accessory drive (CVAD) having a group of traction planets. Each traction planet has a tiltable axis of rotation. The CVAD has a skew actuator operably coupled to each of the traction planets. In one embodiment, the method includes the step of determining a skew actuator command signal. The command signal is based at least in part on a set point for the desired speed. The method also includes the step of applying the skew actuator command signal to the skew actuator to thereby adjust the skew condition of the traction planets.

[0019] One aspect of the invention relates to a traction planet assembly having a traction planet with a central bore. The traction planet assembly can have a planet axle arranged in the central bore. The planet axle has a first end and a second end. In one embodiment, the traction planet assembly has a first leg coupled to the first end of the planet axle. The first leg can be substantially non-rotatable with respect to the planet axle. The traction planet assembly can have a second leg that is coupled to the second end of the planet axle. The second leg can be substantially rotatable with respect to the planet axle.

[0020] Another aspect of the invention concerns a traction planet assembly having a traction planet with a central bore. In one embodiment, the traction planet assembly has a planet axle that is arranged in the central bore. The planet axle can have a first end and a second end. The first and second ends can be provided with inner bores. The traction planet assembly can have a shift reaction ball that is received in each of the inner bores. In one embodiment, the traction planet assembly has a first leg that is coupled to the first end of the planet axle. The traction planet assembly can also have a second leg that is coupled to the second end of the planet axle. The first and second legs are provided with tapered sides.

[0021] Yet another aspect of the invention involves a traction sun assembly for a continuously variable transmission (CVT) having a group of traction planet assemblies. The traction sun assembly includes a traction sun that is coaxial with a longitudinal axis of the CVT. The traction sun can be radially inward of, and in contact with, each of the traction planet assemblies. In one embodiment, the traction sun assembly includes a shift cam that is operably coupled to the traction sun. The traction sun assembly can also include a group of anti-rotation inserts attached to the shift cam.

[0022] One aspect of the invention concerns a carrier member for a continuously variable transmission (CVT) having a group of traction planets. The carrier member can have a substantially bowl-shaped body with a central bore. In one embodiment, the carrier member can have a number of radially offset slots arranged angularly about the central bore. Each of the radially offset slots can have a linear offset from a centerline of the bowl-shaped body.

[0023] In another aspect, the invention concerns a skew actuator for a continuously variable transmission (CVT) having a skew control system. The skew actuator can have a hydraulic piston coupled to the CVT. In one embodiment, the skew actuator has a hydraulic control valve in fluid communication with the hydraulic piston. The skew actuator can also have a spool actuator that is coupled to the hydraulic control valve. The spool actuator can be configured to adjust the hydraulic control valve based at least in part on a desired skew condition of the CVT.

[0024] Another aspect of the invention relates to a skew control system for a continuously variable accessory drive (CVAD) having a group of traction planets. The skew control system includes a sensor configure to receive data from a CVAD. The skew control system can include a skew actuator configured to communicate with a control module. The skew actuator can be further configured to apply a skew condition to each of the traction planets in a CVAD. The skew control system can also include a skew controller in communication with the control module. The skew controller can be configured to determine a skew actuator command signal based at least in part on a signal from the sensor. The skew actuator command signal is configured to control an output speed of a CVAD.

BRIEF DESCRIPTION OF THE FIGURES

[0025] Figure 1 is a perspective view of an inventive embodiment of a continuously variable accessory drive (CVAD) having a skew control system.

[0026] Figure 2 is a cross-sectional perspective view of a continuously variable transmission (CVT) that can be used with the CVAD of Figure 1.

[0027] Figure 3 is an exploded perspective view of the CVT of Figure 2.

[0028] Figure 4 is a cross-sectional view of the CVT of Figure 2.

[0029] Figure 5 is a partial cross-sectional perspective view of a variator subassembly that can be used in the CVT of Figure 2.

[0030] Figure 6 is a cross-sectional view of certain components of the CVT of Figure 2.

[0031] Figure 7 is a cross-sectional Detail view A of certain components of the variator subassembly of Figure 5.

[0032] Figure 8 is a perspective view of a carrier retaining ring that can be used with the variator subassembly of Figure 5.

[0033] Figure 9 is a perspective view of an inventive embodiment of a clevis member that can be used with the CVT of Figure 2.

[0034] Figure 10 is a perspective view of an inventive embodiment of a carrier member that can be used with the variator subassembly of Figure 5.

[0035] Figure 11 is a cross-sectional view of a traction planet assembly that can be used with the variator subassembly of Figure 5.

[0036] Figure 12A is a perspective view of an inventive embodiment of a leg that can be used in the traction planet assembly of Figure 11.

[0037] Figure 12B is a cross-section view A-A of the leg of Figure 12A.

[0038] Figure 13 is a cross-sectional perspective view of a traction sun assembly that can be used with the variator subassembly of Figure 5.

[0039] Figure 14 is an exploded, cross-sectional, perspective view of the traction sun assembly of Figure 13.

[0040] Figure 15 is a cross-sectional view of an inventive embodiment of a continuously variable transmission (CVT) having a skew-based control system.

[0041] Figure 16 is a perspective view of a variator subassembly of the CVT of Figure 15.

[0042] Figure 17 is a cross-sectional view of the variator subassembly of Figure 16.

[0043] Figure 18 is an exploded-perspective view of the variator subassembly of Figure 16.

[0044] Figure 19 is a plan view of the variator subassembly of Figure 16.

[0045] Figure 20A is a plan view of an inventive embodiment of a carrier member that can be used with the variator subassembly of Figure 16.

[0046] Figure 20B is a cross-sectional view of the carrier member of Figure 20A.

[0047] Figure 20C is a perspective view of the carrier member of Figure 20A.

[0048] Figure 21A is a plan detail view B of a radially offset slot of the carrier member of Figure 20A.

[0049] Figure 21B is a schematic illustration of the radially offset slot of Figure 21A.

[0050] Figure 21C is another schematic illustration of the radially offset slot of Figure 21A.

[0051] Figure 21D is yet another schematic illustration of the radially offset slot of Figure 21A.

[0052] Figure 21E is a plan view of another embodiment of a radially offset slot of the carrier member of Figure 20A.

[0053] Figure 21F is a schematic illustration of the radially offset slot of Figure 21E.

[0054] Figure 21G is another schematic illustration of the radially offset slot of Figure 21E.

[0055] Figure 21H is yet another schematic illustration of the radially offset slot of Figure 21E.

[0056] Figure 22 is a cross-sectional view of an embodiment of a traction planet assembly that can be used with the variator subassembly of Figure 16.

[0057] Figure 23 is a perspective view of an embodiment of a housing member that can be used with the CVT of Figure 2 or Figure 15.

[0058] Figure 24 is another perspective view of the housing member of Figure 23.

[0059] Figure 25 is a flow chart of a skew-based control process that can be used with the CVT of Figure 2 or Figure 15.

[0060] Figure 26 is a chart representing a look-up table that can be used in a subprocess of the skew-based control process of Figure 25.

[0061] Figure 27 is a flow chart of an actuator subprocess that can be used with the skew-based control process of Figure 25.

[0062] Figure 28A is a schematic illustration of an inventive embodiment of a skew-based control system.

[0063] Figure 28B is a schematic illustration of an inventive embodiment of a skew actuator that can be used with the skew-based control system of Figure 28A.

[0064] Figure 29A is a schematic illustration of certain electronic hardware that can be used with the skew-based control system of Figure 28.

[0065] Figure 29B is a flow chart of a skew-based control process that can be used with the CVT of Figure 2 or Figure 15.

[0066] Figure 29C is another flow chart of a skew-based control process that can be used with the CVT of Figure 2 or Figure 15.

[0067] Figure 29D is yet another flow chart of a skew-based control process that can be used with the CVT of Figure 2 or Figure 15.

[0068] Figure 30 is a perspective view of an inventive embodiment of a continuously variable transmission (CVT) having a skew-based control system.

[0069] Figure 31 is a cross-sectional perspective view of the CVT of Figure 30.

[0070] Figure 32 is a cross-sectional view of the CVT of Figure 30.

[0071] Figure 33 is an exploded, cross-sectional, perspective view of the CVT of Figure 30.

[0072] Figure 34 is a cross-section view of a variator subassembly that can be used with the CVT of Figure 30.

[0073] Figure 35 is an exploded, cross-sectional, perspective view of the variator subassembly of Figure 34.

[0074] Figure 36 is an exploded, perspective view of an embodiment of a traction planet assembly that can be used with the variator subassembly of Figure 34.

[0075] Figure 37 is a cross-sectional view of the traction planet assembly of Figure 36.

[0076] Figure 38 is a perspective view of an inventive embodiment of a carrier insert that can be used with the variator subassembly of Figure 34.

[0077] Figure 39 is a perspective view of a carrier member that can be used with the variator subassembly of Figure 34.

[0078] Figure 40 is a cross-sectional perspective view of the carrier member of Figure 39.

[0079] Figure 41 is a perspective view of an embodiment of a skew driver that can be used with the CVT of Figure 30.

[0080] Figure 42 is a cross-sectional view B-B of the skew driver of Figure 41.

[0081] Figure 43 is a schematic illustration of an inventive embodiment of a continuously variable transmission (CVT) having a skew-based control system.

[0082] Figure 44 is a schematic illustration of another inventive embodiment of a continuously variable transmission (CVT) having a skew-based control system.

[0083] Figure 45 is a cross-sectional view of an embodiment of a variator.

[0084] Figure 46 is a partial cross-sectional perspective view of a traction sun assembly that can be used in the variator of Figure 45.

[0085] Figure 47 is a cross-sectional view of the traction sun assembly of Figure 46.

[0086] Figure 48 is a cross-sectional detail view C of the traction sun assembly of Figure 46.

[0087] Figure 49 is a cross-section view of certain components of a variator that can be used with the CVT of Figure 2, Figure 15, and/or Figure30.

[0088] Figure 50 is a cross-sectional view of another embodiment of carrier members that can be used with the CVT of Figure 2, Figure 15, and/or Figure 30.

[0089] Figure 51 is a cross-section view C-C of the carrier members of Figure 50.

[0090] Figure 52 is a cross-sectional view of one more embodiment of carrier members that can be used with the CVT of Figure 2, Figure 15, and/or Figure 30.

DETAILED DESCRIPTION OF CERTAIN INVENTIVE EMBODIMENTS

[0091] The preferred embodiments will be described now with reference to the accompanying figures, wherein like numerals refer to like elements throughout. The terminology used in the descriptions below is not to be interpreted in any limited or restrictive manner simply because it is used in conjunction with detailed descriptions of certain specific embodiments of the invention. Furthermore, embodiments of the invention can include several novel features, no single one of which is solely responsible for its desirable attributes or which is essential to practicing the inventions described. Certain CVT embodiments described here are generally related to the type disclosed in U.S. Patent Nos. 6,241,636; 6,419,608; 6,689,012; 7,011,600; 7,166,052; U.S. Patent Application Nos. 11/243,484; 11/543,311; 12/198,402 and Patent Cooperation Treaty patent applications PCT/US2007/023315, PCT/IB2006/054911, PCT/US2008/068929, and PCT/US2007/023315, PCT/US2008/074496. The entire disclosure of each of these patents and patent applications is hereby incorporated herein by reference.

[0092] As used here, the terms “operationally connected,” “operationally coupled”, “operationally linked”, “operably connected”, “operably coupled”, “operably linked,” and like terms, refer to a relationship (mechanical, linkage, coupling, etc.) between elements whereby operation of one element results in a corresponding, following, or simultaneous operation or actuation of a second element. It is noted that in using said terms to describe inventive embodiments, specific structures or mechanisms that link or couple the elements are typically described. However, unless otherwise specifically stated, when one of said terms is used, the term indicates that the actual linkage or coupling may take a variety of forms, which in certain instances will be readily apparent to a person of ordinary skill in the relevant technology.

[0093] For description purposes, the term “axial” as used here refers to a direction or position along an axis that is parallel to a main or longitudinal axis of a transmission or variator. The term “radial” is used here to indicate a direction or position that is perpendicular relative to a longitudinal axis of a transmission or variator. For clarity and conciseness, at times similar components labeled similarly (for example, bearing 152A and bearing 152B) will be referred to collectively by a single label (for example, bearing 152).

[0094] It should be noted that reference herein to “traction” does not exclude applications where the dominant or exclusive mode of power transfer is through “friction.” Without attempting to establish a categorical difference between traction and friction drives here, generally these may be understood as different regimes of power transfer. Traction drives usually involve the transfer of power between two elements by shear forces in a thin fluid layer trapped between the elements. The fluids used in these applications usually exhibit traction coefficients greater than conventional mineral oils. The traction coefficient (μ) represents the maximum available traction forces which would be available at the interfaces of the contacting components and is a measure of the maximum available drive torque. Typically, friction drives generally relate to transferring power between two elements by frictional forces between the elements. For the purposes of this disclosure, it should be understood that the CVTs described here may operate in both tractive and frictional applications. For example, in the embodiment where a CVT is used for a bicycle application, the CVT can operate at times as a friction drive and at other times as a traction drive, depending on the torque and speed conditions present during operation.

[0095] Embodiments of the invention disclosed here are related to the control of a variator and/or a CVT using generally spherical planets each having a tiltable axis of rotation that can be adjusted to achieve a desired ratio of input speed to output speed during operation. In some embodiments, adjustment of said axis of rotation involves angular displacement of the planet axis in a first plane in order to achieve an angular adjustment of the planet axis in a second plane, wherein the second plane is substantially perpendicular to the first plane. The angular displacement in the first plane is referred to here as “skew”, “skew angle”, and/or “skew condition”. For discussion purposes, the first plane is generally parallel to a longitudinal axis of the variator and/or the CVT. The second plane can be generally perpendicular to the longitudinal axis. In one embodiment, a control system coordinates the use of a skew angle to generate forces between certain contacting components in the variator that will tilt the planet axis of rotation substantially in the second plane. The tilting of the planet axis of rotation adjusts the speed ratio of the variator. The aforementioned skew angle, or skew condition, can be applied in a plane substantially perpendicular to the plane of the page of Figure 4, for example. Embodiments of transmissions employing certain inventive skew control systems for attaining a desired speed ratio of a variator will be discussed.

[0096] One aspect of the torque/speed regulating devices disclosed here relates to drive systems wherein a prime mover drives various driven devices. The prime mover can be, for example, an electrical motor and/or an internal combustion engine. For purposes of description here, an accessory includes any machine or device that can be powered by a prime mover. For purposes of illustration and not limitation, said machine or device can be a power takeoff device (PTO), pump, compressor, generator, auxiliary electric motor, etc. Accessory devices configured to be driven by a prime mover may also include alternators, water pumps, power steering pumps, fuel pumps, oil pumps, air conditioning compressors, cooling fans, superchargers, turbochargers and any other device that is typically powered by an automobile engine. As previously stated, usually, the speed of a prime mover varies as the speed or power requirements change; however, in many cases the accessories operate optimally at a given, substantially constant speed. Embodiments of the torque/speed regulating devices disclosed here can be used to control the speed of the power delivered to the accessories powered by a prime mover.

[0097] For example, in some embodiments, the speed regulators disclosed here can be used to control the speed of automotive accessories driven by a pulley attached to the crankshaft of an automotive engine. Usually, accessories must perform suitably both when the engine idles at low speed and when the engine runs at high speed. Often accessories operate optimally at one speed and suffer from reduced efficiency at other speeds. Additionally, the accessory design is compromised by the need to perform over a large speed range rather than an optimized narrow speed range. In many cases when the engine runs at a speed other than low speed, accessories consume excess power and, thereby, reduce vehicle fuel economy. The power drain caused by the accessories also reduces the engine's ability to power the vehicle, necessitating a larger engine in some cases.

[0098] In other situations, inventive embodiments of the torque/speed regulating devices disclosed here can be used to decrease or increase speed and/or torque delivered to the accessories for achieving optimal system performance. In certain situations, inventive embodiments of the torque/speed regulating devices disclosed here can be used to increase speed to the accessories when the prime mover runs at low speed and to decrease speed to the accessories when the prime mover runs at high speed. Thus, the design and operation of accessories can be optimized by allowing the accessories to operate at one, substantially favorable speed, and the accessories need not be made larger than necessary to provide sufficient performance at low speeds. The accessories can also be made smaller because the torque/speed regulating devices can reduce speed to the accessories when the prime mover runs at high speed, reducing the stress load the accessories must withstand at high rpm. Because the accessories are not subjected to high speeds, their expected service life can increase substantially. In some cases, smoother vehicle operation results because the accessories do not have to run at low or high speed. Further, a vehicle can operate more quietly at high speed because the accessories run at a lower speed.

[0099] The torque/speed regulators disclosed here can facilitate reducing the size and weight of the accessories as well as the prime mover, thereby reducing the weight of the vehicle and thus increasing fuel economy. Further, in some cases, the option to use smaller accessories and a smaller prime mover lowers the cost of these components and of the vehicle. Smaller accessories and a smaller prime mover can also provide flexibility in packaging and allow the size of the system to be reduced.

Embodiments of the torque/speed regulators described here can also increase fuel economy by allowing the accessories to operate at their most efficient speed across the prime mover operating range. Finally, the torque/speed regulators increase fuel economy by preventing the accessories from consuming excess power at any speed other than low.

[0100] Referring now to **Figures 1 and 2**, in one embodiment a continuously variable accessory drive (CVAD) 10 can include a continuously variable transmission (CVT) 12 coupled to an alternator/generator 14. In one embodiment, the alternator/generator 14 can be, as an illustrative example, a C.E. Niehoff 1224-3 alternator. In one embodiment, the CVT 12 can be provided with a skew actuator 16 and a set of speed sensors 18 that are configured to communicate with a skew-based control system (for example, Figures 25-29). The CVT 12 can be provided with a lubrication manifold 20 and a lubrication sump 22 that are adapted to couple to a lubrication and cooling system (not shown). In one embodiment, a pulley cover 23 can be arranged between the CVT 12 and the alternator/generator 14. The pulley cover 23 can provide structural attachment of the CVT 12 to the alternator/generator 14, among other things. The pulley cover 23 is adapted to radially surround a drive pulley 24. The drive pulley 24 is configured to receive a power input, for example, from a belt (not shown). In some embodiments, the pulley cover 23 is adapted to provide access to the pulley for a belt.

[0101] Turning now to **Figures 3-4**, in one embodiment, the CVT 12 includes a housing 26 adapted to couple to a housing cap 28. The housing 26 and the housing cap 28 are configured to operably couple to, and substantially enclose, a variator subassembly 30. The variator subassembly 30 is coupled to a first traction ring 32 and a second traction ring 34. The first traction ring 32 is coupled to a first load cam roller assembly 36. The second traction ring 34 can be coupled to a second load cam roller assembly 38. In one embodiment, the first load cam roller assembly 36 is coupled to an input cam driver 40. The second load cam roller assembly 38 can be coupled to an output driver 42. In one embodiment the input cam driver 40 is coupled to the drive pulley 24. Each of the load cam roller assemblies 36 and 38 can be provided with a toothed and/or notched outer periphery that can be arranged to be in proximity to each of the speed sensors 18. The variator subassembly 30 can be operably coupled to the skew actuator 16 via a clevis 43.

[0102] In one embodiment, the CVT 12 can be provided with a main shaft 44 that is substantially aligned with a longitudinal axis of the CVT 12. The main shaft 44 can be provided with a keyed bore 45 that can be adapted to receive, for example, a shaft of the alternator/generator 14. The drive pulley 24 can be radially supported on one end of the main shaft 44 with a first bearing 46 and a second bearing 48. In some embodiments, a shim 50 can be placed between the bearings 46, 48. In one embodiment, the CVT 12 is provided with a thrust bearing 52 coupled to the main shaft 44. The thrust bearing 52 can couple to the pulley 24. The thrust bearing 52 can be adapted to provide axial support for, and react axial forces from, certain components of the CVT 12. The first and second bearings 46, 48 and the shim 50 can be configured to share a portion of the axial loads induced on the thrust bearing 52. The sharing of the axial loads can extend the life of the thrust bearing 52 and can prevent overload of the thrust bearing 52, among other things.

[0103] In one embodiment, the variator subassembly 30 is provided with a number of traction planet assemblies 54 arranged angularly about the main shaft 44. The variator subassembly 30 can have a traction sun assembly 56 arranged coaxial about the main shaft 44. The traction sun assembly 56 can be configured to operably couple to each of the traction planet assemblies 54. The traction sun assembly 56 can be arranged radially inward of each of the traction planet assemblies 54. In some embodiments, the traction sun assembly 56 is adapted to move axially along the main shaft 44. In one embodiment, the variator subassembly 30 can include a first carrier member 58 operably coupled to a second carrier member 60. The first and second carrier members 58, 60 are adapted to support each of the traction planet assemblies 54. In one embodiment, the first carrier member 58 can be coupled to a first carrier member cap 62. The second carrier member 60 can be coupled to a second carrier member cap 64. The carrier member caps 62 and 64 can be configured to operably couple to the traction planet assemblies 54. The carrier member caps 62, 64 can be configured to react forces generated during the shifting of the CVT 12.

[0104] In some embodiments, the carrier member caps 62, 64 are integral with the carrier members 58, 60, respectively. In other embodiments, the carrier member caps 62, 64 are rigidly and permanently attached to the carrier members 58, 60. In one embodiment, the carrier member caps 62, 64 are separate components from the carrier members 58, 60 to enable the use of different materials for the components. For example, the carrier member 58 can be made of aluminum while the carrier member cap 62 can be made of steel. As a separate component, the carrier member cap 62 may also facilitate assembly of the traction planet assemblies 54 with the carrier member 58. In some embodiments, configuring the carrier member caps 62 as separate components can simplify the manufacture of the first and second carrier members 58, 60.

[0105] Referring to **Figure 5**, in one embodiment the variator subassembly 30 includes a carrier retaining ring 66 that is adapted to couple to the first and second carrier members 58, 60. The carrier retaining ring 66 can be coupled to the housing 26 and can be configured to be substantially non-rotatable with respect to the longitudinal axis of the CVT 12. In one embodiment, each of the traction planet assemblies 54 includes at least one leg 68 that is operably coupled to a planet axle 70. Each of the legs 68 is adapted to operably couple to the traction sun assembly 56. In one embodiment, the traction sun assembly 56 includes a number of anti-rotation inserts 72. The anti-rotation inserts 72 can be configured to substantially flank each of the legs 68. The anti-rotation inserts 72 can be coupled to a first shift cam 74. In some embodiments, the anti-rotation inserts 72 can be coupled to a second shift cam 76. In yet other embodiments, the anti-rotation inserts 72 can be coupled to both the first and second shift cams 74 and 76. The anti-rotation inserts 72 can substantially prevent the shift cams 74 and 76 from rotating during operation of the CVT 12.

[0106] During operation of the CVT 12, a power input can be coupled to the drive pulley 24 with, for example, a belt or chain (not shown). The drive pulley 24 transfers the power input to the input cam driver 40, which transfers power to the first traction ring 32 via the first load cam roller assembly 36. The first traction ring 32 transfers the power to each of the traction planet assemblies 54. Each of the traction planet assemblies 54 delivers power to the second traction ring 34 which transfers power to the output cam driver 42 via the second load cam roller assembly 38. In one embodiment, the output driver 42 delivers power to the main shaft 44. The main shaft 44 can be coupled to, for example, the alternator/generator 14 via the keyed bore 45. A shift in the ratio of input speed to output speed, and consequently a shift in the ratio of input torque to output torque, is accomplished by tilting the rotational axis of the traction planet assemblies 54 to a tilt angle sometime referred to here as gamma (γ). The tilting of the rotational axis of the traction planet assemblies 54 occurs in substantially in the plane of the page of Figure 4, for example. The tilting of the rotational axis of the traction planet assemblies 54 can be accomplished by rotating the second carrier member 60 with respect to the first carrier member 58 about the longitudinal axis. This relative angular rotational displacement is sometimes referred to here as β. The rotation of the second carrier member 60 with respect to the first carrier member 58 induces a skew angle, a condition sometimes referred to here as a "skew condition", on each of the traction planet assemblies 54. The skew angle can be applied in a plane that is substantially parallel to the longitudinal axis of the CVT 12 (for example, a plane perpendicular to the plane of the page of Figure 4). In one embodiment, the skew angle can be in the range of 0 degrees to 15 degrees. Typically the skew angle is in the range of 0 degrees to 8 degrees.

[0107] Turning now to **Figure 6**, in one embodiment the input cam driver 40 is coupled to the drive pulley 24. The input cam driver 40 can be provided with a number of roller reaction surfaces 78 that can be adapted to operably couple to the first load cam roller assembly 36. The main shaft 44 can be provided with a central lubricant passage 80 that feeds a number of lubricant distribution passages 82A, 82B, 82C. The lubricant distribution passages 82A, 82B, 82C intersect the central lubricant passage 80 and extend radially outward from the center of the main shaft 44. In one embodiment, the main shaft 44 can be provided with a splined portion 84 that is configured to couple to the output cam driver 42. The main shaft 44 can be provided with a shoulder 86 in proximity to one end of the splined portion 84. The main shaft 44 can be provided with a groove 88 on an opposite end of the spline portion 84. In some embodiments, the main shaft is provided with a threaded bore 90 on one end. During assembly of the CVT 12, the variator subassembly 30 is arranged coaxially with the main axle 44. An assembly tool (not shown) is coupled to the threaded bore 90. The assembly tool threads into the bore 90 and applies force on the output ring 42 to facilitate the clamping of the output ring 42 and the input ring 40 to a predetermined axial force. At least one clip 92 (Figures 3 and 4) can be placed in the groove 88 to retain the axial preload setting once the assembly tool is removed. In some embodiments, shims (not shown) can be placed in the groove 88 with the clip 92 to retain the axial preload setting.

[0108] Passing now to **Figure 7**, in one embodiment the first carrier member 58 is adapted to couple to the second carrier member 60 via a shoulder bolt 94. The shoulder bolt 94 can be configured to couple to the carrier retaining ring 66. In one embodiment, a shim 96 can be placed under the head of the shoulder bolt 94. The thickness of the shim 96 can be selected to adjust the axial force and/or the axial gap between the first carrier member 58 and the second carrier member 60 upon tightening of the shoulder bolt 94. In one embodiment, it is desirable to have minimal axial force between the first carrier member 58 and the second carrier member 60 so that the second carrier member 60 can rotate with respect to the first carrier member 58 about the longitudinal axis while having minimal axial displacement or play between the first carrier member 58 and the second carrier member 60. In some embodiments, the carrier retaining ring 66 is coupled to the housing 26 and is substantially non-rotatable about the longitudinal axis. In other embodiments, a thrust bearing (not shown) can be provided between the first and second carrier members 58 and 60.

[0109] Referring now to **Figure 8**, in one embodiment the carrier retaining ring 66 is a substantially annular ring having a reaction face 98 formed on an inner circumference. The carrier retaining ring 66 can be provided with a flange 100 located on an outer circumference of the substantially annular ring. The flange 100 can be configured to couple to, for example, the housing 26. In one embodiment, the carrier retaining ring 66 is provided with an opening 102 placed substantially between the reaction face 98 and the flange 100. In some embodiments, the reaction face 98 is formed with a number of fastening holes 104 that are adapted to receive the shoulder bolts 94. The flange 100 can be provided with a fastening hole 106 that can be configured to secure the carrier retaining ring 66 to the housing 24.

[0110] Passing now to **Figure 9**, in one embodiment the clevis 43 can be provided with at least one fork 110. The fork 110 extends from a base 112. The base 112 can be provided with a set screw land 114. The clevis 43 can be coupled to the carrier member 58 or to the second carrier member 60. In one embodiment, the base 112 is attached to one of the first or second carrier members 58, 60 with, for example, a set screw (not shown). The fork 110 can be arranged to extend through the opening 102. During operation of the CVT 12 and the actuator 16 can be coupled to the fork 110 to facilitate a change in ratio of the CVT 12. In one embodiment, the change in ratio of the CVT 12 is accomplished by rotating the second carrier member 60 with respect to the first carrier member 58. In some embodiments, the change in ratio of the CVT 12 is accomplished by rotating the first carrier member 58 with respect to the second carrier member 60.

[0111] Turning now to **Figure 10**, in one embodiment, the carrier member 58 can be a substantially bowl-shaped body having a flange 120. A number of support fingers 122 can extend radially inward from the flange 120 to thereby form a cavity of the bowl-shaped body. Each finger 122 is flanked on each side by a reaction surface 124. Each finger can also be provided with a fastening hole 126. The fastening hole 126 can facilitate the coupling of the first carrier member cap 62 to the carrier member 58. In one embodiment, the flange 120 included a number of holes 128 and slots 130. In some embodiments, the holes 128 and the slots 130 can be arranged about the flange 120 so that each hole 128 is flanked by the slots 130 and vice versa. In one embodiment, the carrier member 58 and the carrier member 60 are substantially similar. Once assembled the holes 128 on the carrier member 58 can align with the slots 130 of the carrier member 60 and vice versa. The flange 120 can be provided with a notch 132. The notch 132 can be adapted to couple to the clevis 43. The flange 120 can be provided with a set screw hole 134 arranged to intersect the notch 132 and the outer periphery of the flange 120. The set screw hole 134 can facilitate the coupling of the clevis 43 to the carrier member 58 with, for example, a set screw (not shown). The carrier member 58 can have a number of clearance openings 140. In one embodiment, the clearance openings 140 are configured to cooperate with each of the traction planet assemblies 54.

[0112] Referring now to **Figures 11-12B**, in one embodiment the traction planet assembly 54 includes a substantially spherical traction planet 150 having a central bore. The traction planet 150 can be operably coupled to the planet axle 70 with bearings 152. In some embodiments, a spacer 154 can be operably coupled to the planet axle 70 and located between the bearings 152. The planet axle 70 can be coupled on each end to the legs 68. A skew reaction roller 156 can be operably coupled to each of the planet axle 70. A shift reaction ball 158 can be pressed into a bore 160 formed on each end of the planet axle 70. A shift cam roller 162 can be operably coupled to each leg 68. The shift cam roller 162 can be coupled to a shift cam roller axle 164. The shift cam roller axle 164 can be coupled to a shift cam roller axle bore 166 formed on the leg 68. The shift cam roller 162 can be positioned in a slot 168 formed on one end of the leg 68. In one embodiment, the slot 168 is substantially perpendicular to the shift cam roller axle bore 166. The leg 68 can be provided with a planet axle bore 170. The planet axle bore 170 can be formed on the leg 68 at an end opposite that of the slot 166. The leg 68 can be provided with a skew reaction roller clearance shoulder 172. The leg 68 can have a side 174 that has an angular taper when viewed in the plane of the page of Figure 12B. In one embodiment, the side 174 has an angle 176 with respect to vertical in the range of about 5 degrees to 10 degrees.

[0113] Turning now to **Figures 13** and **14**, in one embodiment the traction sun assembly 56 includes a traction sun 180 that is operably coupled to the first and second shift cams 74 and 76. The shift cams 74 and 76 can be arranged to substantially flank the traction sun 180. In one embodiment, the shift cams 74 and 76 are substantially similar. The traction sun assembly 56 can include a set of bearings 184. Each bearing 184 can be coupled to a bearing race 186. The bearing race 186 is configured to couple to a shoulder 188 formed on an inner diameter of the traction sun 180. In one embodiment, the bearing races 186 are coupled to a spring 190. The spring 190 can facilitate the axial preload of the bearing races 186 thereby applying an axial preload force to the bearings 184 and the shift cams 74 and 76. The traction sun assembly 56 can be provided with bearings 192. The bearings 192 can be adapted to facilitate the coupling of the traction sun assembly 56 to the main shaft 44. In one embodiment, the traction sun assembly includes a number of anti-rotation spacers 194. Each anti-rotation spacer 194 can be coupled to the shift cams 182. In one embodiment, the shift cams 74 and 76 are provided with a number of seats 196 configured to couple to the anti-rotation spacers 194. Each anti-rotation spacer 194 is provided with a hole 198. Each seat 196 is provided with a hole 200. The holes 198 and 200 are adapted to facilitate the coupling of the anti-rotation inserts 194 to the shift cam 74. In one embodiment, the shift cam 74 can be a generally disc-shaped body having a shoulder 202 extending from one end. A bearing race 204 can be formed on the shoulder 202. The bearing race 204 can be adapted to couple to the bearing 184. In some embodiments, the shift cam 74 can be provided with a cam surface 206. The cam surface 206 can have a substantially curved profile when viewed in cross-section in the plane of Figure 14.

[0114] Passing now to **Figure 15**, in one embodiment a CVT 1000 can include a housing 1002 coupled to a housing cap 1004. The housing 1002 and the housing cap 1004 can be configured to operably couple to, and substantially enclose, a variator subassembly 1006. The variator subassembly 1006 can be coupled to a first traction ring 1008 and a second traction ring 1010. The first traction ring 1008 can be coupled to a first load cam roller assembly 1012. The second traction ring 1010 can be coupled to a second load cam roller assembly 1014. In one embodiment, the first load cam roller assembly 1012 is coupled to an input cam driver 1016. The second load cam roller assembly 1014 can be coupled to an output driver 1018. In one embodiment, the input cam driver 1016 can be coupled to the drive pulley 24. Each of the load cam roller assemblies 1012 and 1014 can be provided with a toothed and/or notched outer periphery that can be configured to be in proximity to each of the speed sensors 18. The variator subassembly 1006 can be operably coupled to the skew actuator 16 with the clevis 43 (Figure 3). In one embodiment, the CVT 1000 can be provided with a main shaft 1020 that is substantially aligned with a longitudinal axis 1022 of the CVT 1000. The main shaft 1020 can be provided with a keyed bore 1025 that can be adapted to receive, for example, a shaft of the alternator/generator 14, or any other accessory device. The drive pulley 24 can be operably coupled to the main shaft 1020. In one embodiment, the coupling of the drive pulley 24 to the main shaft 1020 is substantially similar to the coupling of the drive pulley 24 to the main shaft 44.

[0115] Referring to **Figures 15-18**, in one embodiment, the variator subassembly 1006 can include a number of traction planet assemblies 1024 arranged angularly about the longitudinal axis 1022. The variator subassembly 1006 can include a traction sun assembly 1026 arranged coaxial about the main shaft 1020. The traction sun assembly 1026 can be located radially inward of each of the traction planet assemblies 1024. In one embodiment, the traction sun assembly 1026 can be adapted to be substantially axially fixed along the main shaft 1020. In one embodiment, the variator subassembly 1006 can include a first carrier member 1028 operably coupled to a second carrier member 1030. The first and second carrier members 1028, 1030 are configured to support each of the traction planet assemblies 1024.

[0116] In one embodiment, the first carrier member 1028 is coupled to a first carrier member cap 1032. The second carrier member 1030 can be coupled to a second carrier member cap 1034. The carrier member caps 1032, 1034 are adapted to operably couple to the traction planet assemblies 1024. In one embodiment, the variator subassembly 1006 can include a carrier retaining ring 1036. The carrier retaining ring 1036 can be configured to couple to the first and second carrier members 1028, 1030. The carrier retaining ring 1036 can be provided with a flange 1038. The flange 1038 can be coupled to the housing 1002 and can be configured to be substantially non-rotatable with respect to the longitudinal axis 1022. The carrier retaining ring 1036 can be provided with an opening 1040 through which the clevis 43 can be placed to couple to, for example, the second carrier member 1030. A number of shoulder bolts 1042 can be provided to operably couple the first and second carrier members 1028, 1030 to the carrier retaining ring 1036. The coupling of the first and second carrier members 1028, 1030 to the carrier retaining ring 1036 can be configured in a substantially similar manner as the coupling of the first and second carrier members 58, 60 to the carrier retaining ring 66 (Figure 7).

[0117] During operation of the CVT 1000, a power input can be coupled to the drive pulley 24 with, for example, a belt or chain (not shown). The drive pulley 24 can transfer the power input to the input cam driver 1016. The input cam driver 1016 can transfer power to the first traction ring 1008 via the first load cam roller assembly 1012. The first traction ring 1008 transfers the power to each of the traction planet assemblies 1024. Each of the traction planet assemblies 1024 delivers power to the second traction ring 1010. The second traction ring 1010 delivers power to the output driver 1018. The output driver 1018 is configured to deliver power to the main shaft 1020 so that power can be transferred out of the CVT 1000. A shift in the ratio of the input speed to the output speed, and consequently a shift in the ratio of the input torque to the output torque can be accomplished by tilting the rotational axis of the traction planet assemblies 1024 to a tilt angle (γ). The tilting of the rotational axis of the traction planet assemblies 1024 can be facilitated by rotating the first carrier member 1028 with respect to the second carrier member 1030. The rotation of the first carrier member 1028 with respect to the second carrier member 1030 generates a skew condition of the type generally described in U.S. Patent Application 12/198,402 filed on August 26, 2008, the entire disclosure of which is hereby incorporated herein by reference. A skew condition can be applied to the traction planet assemblies 1024 by two events, occurring separately or in combination. One event is a change in the angular rotation (β) of the carrier member 1028, and the other event is a change in the tilt angle (γ) of the traction planet assemblies 1024. For a constant angular rotation (β) of the carrier member 1028, the skew condition can approach a zero skew-angle condition as the rotational axis of the traction planet assemblies 1024 tilts. The rotational axis of the traction planet assemblies 1024 can stop tilting when a zero skew-condition is reached. The zero-skew condition is an equilibrium condition for the tilt angle (γ).

[0118] Referring still to **Figures 15-18**, in one embodiment the traction sun assembly 1026 can include a traction sun 1044 operably coupled to first and second traction sun supports 1046 with bearings, for example. The traction sun supports 1046 can be adapted to contact the first and second carrier members 1028, 1030. The first and second carrier members 1028, 1030 can constrain and/or limit axial motion of the traction sun assembly 1044. In one embodiment, the traction sun supports 1046 can be coupled to wave springs (not shown) positioned between the traction sun supports 1046 and the first and second carrier members 1028, 1030. The wave springs can energize during operation of the CVT 1000 to provide a minimum axial travel to the traction sun assembly 1026. In some embodiments, the traction sun supports 1046 are coupled to the first and second carrier members 1028 and 1030 via a screw lead (not shown) so that a rotation of either the first or second carrier members 1029, 1030 tends to axially displace the traction sun assembly 1026. In other embodiments, an actuator (not shown) can be coupled to the traction sun assembly 1026 to facilitate a change in the axial position of the traction sun assembly 1026 based at least in part on the tilt angle (γ) of the traction planet assemblies 1024 of the CVT 1000. In yet other embodiments, an actuator (not shown) can be coupled to the traction sun assembly 1026 to facilitate a change in the axial position of the traction sun assembly 1026 that is substantially random with respect to the tilt angle (γ) of the traction planet assemblies 1024. The aforementioned methods of axially positioning the traction sun assembly 1026 can increase the expected life of the traction sun 1044, for example, by distributing operational loads over a larger area of the surface of the traction sun 1044 than would otherwise be achievable.

[0119] Turning now to **Figure 19-21C**, in one embodiment the first carrier member 1028 can be provided with a number of radially offset slots 1050. The second carrier member 1030 can be provided with a number of radial slots 1052. The radial slots 1052 are shown in dashed lines in Figure 19. The radially offset slots 1050 and the radial slots 1052 are sized to accommodate certain components of the traction planet assemblies 1024, for example a skew reaction roller 1100 (Figure 22). For discussion purposes, the arrangement of the radially offset slots 1050 with respect to the radial slots 1052 can be shown as projections in a plane perpendicular to the longitudinal axis 1022. The longitudinal axis 1022 is perpendicular to the plane of the page of Figure 19. A radial construction line 1054 can be shown perpendicular to the longitudinal axis 1022. The construction line 1054 radially passes through a center 1056 of the first and second carrier members 1028, 1030. Likewise, a second construction line 1058 can pass through the center 1056. The construction line 1058 substantially bisects the radial slots 1052. A radially offset construction line 1060 is parallel to the construction line 1054. The radially offset construction line 1060 is perpendicular to the longitudinal axis 1022. An offset distance 1062 separates the radially offset construction line 1060 from the construction line 1054. In one embodiment, the offset distance 1062 is in the range of about 5mm to 20mm. In some embodiments, the offset distance 1062 is between 16-18mm. In some embodiments, the offset distance 1062 is proportional to the width of the radially offset slot 1050. For example, the offset distance 1062 can be about equal to the width of the radially offset slot 1050. The radially offset construction line 1060 substantially bisects the radially offset slot 1050. The radially offset construction line 1060 intersects the second construction line 1058 to thereby form an angle 1064 (sometimes referred to here as ψ). In one embodiment, the angle (ψ) 1064 can be in the range of 5 degrees to 45 degrees for conditions where the traction planet subassemblies 1024 are at a tilt angle (γ) substantially equal to zero. Preferably, the angle (ψ) 1064 is in the range of 10 degrees to 20 degrees when the traction planet subassemblies 1024 are at a tilt angle (γ) substantially equal to zero.

[0120] Referring still to Figure 19, in one embodiment the first carrier member 1028 can be provided with a number of clearance openings 1066. The second carrier member 1030 can be provided with a number of clearance openings 1068. The clearance openings 1066, 1068 can be adapted to provide clearance to each of the traction planet assemblies 1024. In one embodiment, the clearance opening 1066 is larger than the clearance opening 1068 to provide additional clearance to the traction planet assembly 1024 during operation of the CVT 1000.

[0121] Referring now to Figures 20A-20C, in one embodiment the first carrier member 1028 can be a substantially bowl-shaped body having a central bore 1070 and a flange 1072 about the outer periphery of the bowl-shaped body. The flange 1072 can be provided with a number of holes 1074 and a number of slots 1076. The holes 1074 and the slots 1076 can be adapted to facilitate the coupling of the first carrier member 1028 to the second carrier member 1030 with, for example, the shoulder bolts 1042, in such a manner as to allow relative rotational displacement between the carrier members 1028, 1030 while providing axial constraint. The first carrier member 1028 can be provided with a reaction shoulder 1078 arranged about the central bore 1070. In one embodiment, the reaction shoulder 1078 can be configured to contact the traction sun support 1046. The flange 1072 can be provided with a notch 1080. The notch 1080 can be adapted to facilitate the coupling of the first carrier member 1028 to the clevis 43. The first carrier member 1028 can be provided with a number of holes 1082 located on a bottom face of the bowl-shaped body. The holes 1082 can be arranged to facilitate the coupling of the first carrier member cap 1032 to the first carrier member 1028. In one embodiment, each radial slot 1050 is provided with a reaction surface 1084. The reaction surfaces 1084 are configured to facilitate the coupling of the first carrier member 1028 to the traction planet assemblies 1024.

[0122] Referring to Figures 21A- 21D, the construction line 1058 can form the angle (ψ) 1064 with the offset construction line 1060. During operation of the CVT 1000, the carrier members 1028, 1030 can be rotated about the longitudinal axis 1022. The offset construction line 1060 follows the first carrier member 1028 and the construction line 1058 follows the second carrier member 1030. For clarity, the construction lines 1058 and 1060 are depicted in Figures 21B-21D for three angular rotational positions about the longitudinal axis of, for example, the second carrier member 1030 with respect to the first carrier member 1028 (this relative angular rotational position is sometimes referred to here as β). As the carrier members 1028, 1030 are rotated relative to each other, the angle (ψ) 1064 can change and an intersection location 1063 can move radially relative to the construction line 1058. For example, an angle 10640 depicted in Figure 21B is smaller than an angle 10641 depicted in Figure 21D. The angle 10640 is formed between the construction line 1058 and the construction line 1060 when then tilt angle (γ) is less than zero. The angle 10641 is formed between the construction line 1058 and the construction line 1060 when the tilt angle (γ) is greater than zero. In some embodiments, location of the carrier members 1028, 1030 may be reversed in the CVT 1000. Such a reversal may alter the relationship embodied in Figure 21. The intersection location 1063 can be shown at the intersection between the offset construction line 1060 and the construction line 1058. The intersection location 1063 generally corresponds to a skew angle equal to zero, or a "zero-skew condition", for the traction planet subassemblies 1024 at a constant tilt angle (γ). The amount of change of the angle (ψ) 1064 is sometimes an indication of the stability of the tilt angle (γ) of the traction planet assemblies 1024 during operation. A high value for the angle (ψ) 1064 tends to be more stable and exhibit slower shifting than a low angle that tends to be less stable and exhibits faster shifting.

[0123] Referring specifically now to Figure 21E-21H, in one embodiment a radially offset slot 1051 can have a curved profile that generally follows a construction line 1059. In some embodiments, the carrier member 1028 can be provided with the radially offset slots 1051. The curvature of the construction line 1059, and consequently the curvature of the radially offset slot 1051, can be configured to provide the desired control stability and response of the CVT 1000. For illustrative purposes, a construction line 1061 can be shown tangent to the construction line 1059 at an intersection location 1065. The intersection location 1065 is generally at the intersection between the construction line 1058 and the construction line 1059. The angle (ψ) 1064 is shown in Figure 21E between the construction line 1058 and the construction line 1061. In some embodiments, the curvature of the construction line 1059 can be arranged to provide a constant angle (ψ) 1064 between the construction lines 1058 and 1061 as the carrier member 1028 is rotated relative to carrier member 1030 by the angle β about the longitudinal axis. For clarity, the construction lines 1058, 1059, and 1061 are depicted in Figures 21F-21H for three angular rotational positions (β). As the carrier members 1028, 1030 are rotated relative to each other, the angle (ψ) 1064 remains constant and the intersection location 1065 can move radially relative to the construction line 1058. In some embodiments, the angle (ψ) 1064 may vary arbitrarily between the tilt angle (γ) conditions depicted from Figure 21F through Figure 21H. The variation on the construction angle 1064 may be chosen to optimize control conditions of the CVT 1000. The resulting path of the construction line 1059 can be formulated using techniques available to those skilled in the relevant technology.

[0124] Turning now to **Figure 22**, in one embodiment the traction planet assembly 1024 includes a substantially spherical planet 1090 having a central bore. The planet 1090 can be operably coupled to a planet axle 1092 with, for example, bearings 1094. In one embodiment, a spacer 1096 can be placed between the bearings 1094. In some embodiments, the spacer 1096 is integral with the bearings 1094. The bearings 1094 can be retained on the planet axle 1092 with rings 1098. In some embodiments, the rings 1098 can be integral with the bearing 1094. In one embodiment, the traction planet assembly 1024 can include a skew reaction roller 1100 coupled to each end of the planet axle 1092. The skew reaction roller 1100 can be retained on the planet axle 1092 with a collar 1101. In one embodiment, the collar 1101 can be attached to the planet axle 1092 with a press fit or other suitable means of attachment. In other embodiments, the collar 1101 can be restrained by the carrier caps 1032 and 1034 (Figure 15). Each end of the planet axle 1092 can be adapted to receive a shift reaction ball 1102. In one embodiment, the shift reaction ball 1102 is pressed into a hole 1103 formed on each end of the planet axle 1092. In some embodiments, the shift reaction ball 1102 can contact the first carrier member cap 1032 or the second carrier member cap 1034 during operation of the CVT 1000.

[0125] Passing now to **Figures 23** and **24**, in one embodiment the housing 1002 can be a substantially bowl-shaped body 1109 having a flange 1110 formed on a first end and a lubricant supply hub 1112 formed on a second end. The flange 1110 can be configured to couple to a support structure, for example, the pulley cover 23. The lubricant supply hub 1112 can be provided with a lubricant passage 1113. The lubricant passage 1113 can be adapted to couple to an external pump (not shown). The housing 1002 can be provided with a sensor mounting hub 1114 located on the outer periphery of the bowl-shaped body 1009. The sensor mounting hub 1114 can facilitate the mounting of, for example, the speed sensors 18. The speed sensor 18 can be inserted into an access bore 1115 to facilitate the placement of the speed sensor 18 in proximity to the load cam roller assembly 1012. In one embodiment, the housing 1002 can include a lubricant reservoir 1116 attached to the outer periphery of the bowl-shaped body 1009 at a mounting interface 1117. The lubricant reservoir 1116 can be provided with a number of fins 1118. The fins 1118 can facilitate the transfer of heat from a lubricant to the ambient air during operation of, for example, the CVT 12. The lubricant reservoir 1116 can also be provided with a lubricant passage 1119. In some embodiments, the lubricant passage 1119 is adapted to couple to an external pump (not shown). In one embodiment, the housing 1002 can be provided with an actuator mounting hub 1120 located on the outer periphery of the bowl-shaped body 1009. The actuator mounting hub 1120 can be configured to attach to, for example, the actuator 16. The actuator mounting hub can be adapted to facilitate the coupling of the actuator 16 to, for example, the clevis 43.

[0126] Referring now to **Figure 25**, in one embodiment a skew-based control process 2000 can be implemented on, for example, a microprocessor in communication with power electronics hardware of the CVT 1000. In some embodiments, the skew-based control process 2000 can be implemented on a microprocessor in communication with the CVT 12 or other CVT embodiments described herein. The skew-based control process 2000 begins at a block 2002. The skew-based control process 2000 then proceeds to a block 2004 where a desired speed ratio (SR) set point of the CVT 1000 is received. In one embodiment the desired SR set point is received from a user. In some embodiments, the desired SR setpoint is received from predetermined map residing in memory of a controller (for example, see Figure 28A). The skew-based control process 2000 continues to a block 2006 where an angular rotation about the longitudinal axis of, for example, the second carrier member 1030 with respect to the first carrier member

1028 (β) is determined. Next, the skew-based control process 2000 moves to an actuator subprocess 2008 where the angular rotation (β) is applied to the carrier member 1028, for example. Upon completion of the actuator subprocess 2008, the skew-based control process 2000 proceeds to a block 2009 where the actual SR of the CVT 1000 is measured. In one embodiment, the actual SR of the CVT 1000 can be determined by measuring the speed of, for example, the load cam roller assemblies 1012 and 1014, or any other component indicative of input speed and output speed to the CVT 1000. In some embodiments, the actual SR can be calculated based at least in part on a target output speed condition or based at least in part on a target input speed condition. In other embodiments, the actual SR of the CVT 1000 can be determined by measuring the tilt angle (γ) of the planet axle 1092. In yet other embodiments, the actual SR of the CVT 1000 can be determined by measuring an actual torque ratio of the CVT 1000. The actual torque ratio of the CVT 1000 can be determined by measuring the torque of, for example the traction rings 1008 and 1010, or any other component indicative of input torque and output torque to the CVT 1000. In some embodiments, the torque indicative of input torque and output torque can be determined by measuring the torque reacted on the first carrier member 1028 and the second carrier member 1030, respectively. Next, the skew-based control process 2000 proceeds to a decision block 2010 where the measured speed ratio is compared to the desired speed ratio set point to thereby form a comparison value. If the measured speed ratio is not equal to the desired speed ratio set point, the skew-based control process 2000 returns to the block 2006. If the measured speed ratio is equal to the desired speed ratio set point, the skew-based control process 2000 proceeds to an end block 2012. The skew-based control process 2000 remains at the end block 2012 until a new speed ratio set point is received. In some embodiments, the skew-based control process 2000 is configured to operate in an open loop manner; in such a case, the blocks 2009 and 2010 are not included in the skew-based control process 2000.

[0127] Referring to **Figure 26**, in one embodiment the block 2006 can use a look-up table that can be represented by a curve 2007. The curve 2007 depicts an exemplary relationship between the angular rotation (β) and the desired speed ratio of, for example, the CVT 1000. The block 2006 can use the curve 2007 during open loop operation of the skew-based control process 2000. The curve 2007 can be expressed by the equation $y=Ax^2-Bx+C$, where y is the angular rotation (β) and x is the speed ratio. In one embodiment, the values of A, B, and C are 0.5962, 4.1645, and 3.536, respectively. In some embodiments, the values of A, B, and C are 0.5304, 4.0838, and 3.507, respectively. In other embodiments, the values of A, B, and C are related to the dimensions and geometry of the CVT 1000, for example, the position of slot 1050 and 1052 on the carrier members 1028 and 1030, the length of the planet axle 1092, and dimensions of the traction rings 1008 and 1010, among other things. In one embodiment, the block 2006 can be configured to include a well-known PID control process appropriate for closed-loop operation of the skew-based control system 2000. In the closed-loop configuration, the block 2006 determines the angular rotation (β) based at least in part on the comparison (sometimes referred to here as error) between the actual SR and the SR setpoint.

[0128] Referring to **Figure 27**, in one embodiment the actuator subprocess 2008 can begin at a block 2014 and proceed to a block 2015 where a set point for the angular rotation (β) is received. The actuator subprocess 2008 proceeds to a block 2016 where an actuator command signal is determined based at least in part on the angular rotation (β). In one embodiment, a look-up table can be used to convert the angular rotation (β) set point to an actuator command signal. In some embodiments, the actuator command signal can be a voltage or a current. In other embodiments, the actuator command signal can be a change in the position of a cable or a linkage. In some embodiments, an algorithm can be used to derive the actuator command signal from the angular rotation (β) set point. Next, the actuator subprocess 2008 proceeds to a block 2017 where the actuator command signal is sent to an actuator and associated hardware. In one embodiment, a standard serial communication protocol can be used to send the command signal to the actuator hardware. In some embodiments, a cable or a linkage can be used to transmit the command signal to the actuator hardware. The actuator subprocess 2008 then passes to a block 2018 where the carrier member, for example the carrier member 1028, is rotated. Next, the actuator subprocess 2008 passes to a block 2019 where the angular rotation (β) is measured. The actuator subprocess 2008 then proceeds to a decision block 2020 where the measured angular rotation (β) is compared to the set point for the angular rotation (β). If the measured angular rotation (β) is not equal to the angular rotation (β) set point, the actuator subprocess 2008 returns to the block 2016. If the measured angular rotation (β) is equal to the angular rotation (β) set point, the actuator subprocess 2008 then ends at a block 2022, wherein the skew-based control process 2000 can continue at block 2009 as described above with reference to Figure 25. In some embodiments, the actuator subprocess 2008 is configured to operate in an open loop manner; in such a case, the blocks 2019 and 2020 are not included in the subprocess 2008.

[0129] Passing now to **Figure 28A**, in one embodiment a control system 2050 can be configured to control a CVT 2051 coupled to a prime mover 2052 and a load 2053. The CVT 2051 can be configured to accommodate a skew-based control system. In some embodiments, the CVT 2051 is substantially similar to the CVT 12 and/or the CVT 1000. The CVT 2051 can be coupled to a skew actuator 2054. In one embodiment, the skew actuator 2054 can be substantially similar to, for example, the skew actuator 16. In some embodiments, the skew actuator 2054 is a servo actuator. In other embodiments, the skew actuator 2054 can be a mechanical lever (not shown). In yet other embodiments, the skew actuator 2054 can be a hydraulic actuator or an electro-hydraulic actuator (not shown). The control system 2050 can include a number of sensors 2055 in electrical and/or mechanical communication with the CVT 2051, a control module 2056, and a skew control module 2057. In some embodiments, the sensors 2055 can be in communication with the prime mover 2052, the load 2053, and/or the actuator 2054. The sensors 2055 are in communication with the control module 2056. In one embodiment, the control module 2056 is in communication with the skew actuator 2054. The control module 2056 can be configured to communicate with the skew control module 2057. In one embodiment, the skew control module 2057 is configured to perform the skew-based control process 2000. In some embodiments, the control module 2056 is in communication with a data display module 2058 configured to provide a user control interface using one or more displays and/or input devices (not shown).

[0130] Those of skill will recognize that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein, including with reference to the control system 2050 may be implemented as electronic hardware, software stored on a computer readable medium and executable by a processor, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention. For example, various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. Software associated with such modules may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM, or any other suitable form of storage medium known in the art. An exemplary storage medium is coupled to the processor such the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. For example, in one embodiment, the control module 2056 comprises a processor (not shown). The processor of the control module 2056 may also be configured to perform the functions described herein with reference to one or both of the skew control module 2057 and the data display module 2058.

[0131] Turning to **Figure 28B**, in one embodiment the skew actuator 2054 can include a hydraulic piston 2060 in communication with a hydraulic control valve

2061. The hydraulic piston 2060 can be coupled to, for example, the clevis 43. The hydraulic control valve 2061 can provide pressure to ports 2062 and 2063 that can facilitate the movement of the hydraulic piston 2060 to thereby move the clevis 43. The skew actuator 2054 can include a pump 2064 in fluid communication with a reservoir 2065. The pump 2064 can supply pressurized control fluid to a pressure relief valve 2066 and an accumulator 2067 that are adapted to supply pressure control fluid to the hydraulic control valve 2061. In some embodiments, the hydraulic control valve 2061 is a four-way directional control valve that can be in communication with a spool actuator 2068. The spool actuator 2068 can be configured to adjust the hydraulic control valve 2061 based at least in part on a desired skew condition of the CVT 1000, for example. In one embodiment, the spool actuator 2068 can be an electronic servo actuator (not shown). In some embodiments, the spool actuator 2068 can be a manual lever (not shown). In other embodiments, the hydraulic control valve 2061 can be provided with a translatable housing to facilitate an adjustment of the ports 2069 with respect to the internal spool (not shown). The translatable housing can be configured to compensate for steady state errors that may occur during operation of the skew actuator 2054 or during operation of the CVT 1000.

[0132] Referring now to **Figure 29A**, in one embodiment the control module 2056 includes a control device 2070, a communication device 2072, and a microprocessor 2074. In some embodiments, the control device 2070 can be configured to perform a control process such as a well-known proportional/integral gain control process based on a setpoint signal 2076 and a feedback signal 2078. In one embodiment, the setpoint signal 2076 can be configured to represent a desired input speed. In some embodiments, the setpoint signal 2076 can be configured to represent a desired speed ratio of, for example, the CVT 2051. In other embodiments, the setpoint signal 2076 can be configured to represent a desired output speed, a desired input torque, and/or a desired output torque, or any other desired operating characteristic of the CVT 2051. The feedback signal 2078 can be configured to provide an indication of the current operating condition of the CVT 2051. In one embodiment, the feedback signal 2078 is configured to represent the actual speed of the CVT 2051. In some embodiments, the feedback signal 2078 is configured to represent the actual speed ratio of the CVT 2051. In other embodiments, the feedback signal 2078 is configured to provide an indication of the actual output speed, the actual output torque, and/or the actual input torque of the CVT 2051. The control device 2070 can be configured to cooperate with a communication device 2072. The communication device 2072 can include communication hardware such as serial devices, for example, RS232 devices, USB devices, or other well-known communication hardware. The communication device 2072 can be adapted to cooperate with a microprocessor 2074. The microprocessor 2074 can generate an actuator command signal 2080 based at least in part on the setpoint signal 2076 and/or the feedback signal 2078. In one embodiment, the microprocessor 2074 includes hardware configured to operate power electronics in communication with any one or more of the skew actuator 2054, the CVT 2051, the prime mover 2052, and/or the load 2053.

[0133] Referring now to **Figure 29B**, in one embodiment a skew control process 2100 can be implemented on, for example, a microprocessor in communication with power electronics hardware of the CVT 1000. In some embodiments, the skew-based control process 2000 can be implemented on a microprocessor in communication with the CVT 12 or other CVT embodiments described herein. The skew-based control process 2100 begins at a block 2101. The skew-based control process 2100 then proceeds to a block 2102 where a desired tilt angle (γ) set point for the traction planet assemblies 1024 of the CVT 1000, for example, is received. The skew-based control process 2100 continues to a block 2103 where a command signal for a skew actuator is determined. In one embodiment, the command signal is determined by a well-known gain (sometimes referred to as a "PI" or "PID") control process. Next, the skew-based control process 2100 moves to an actuator subprocess 2104 where the command signal is applied to the skew actuator 2054, for example. Upon completion of the actuator subprocess 2104, the skew-based control process 2100 proceeds to a block 2105 where the tilt angle (γ) of the traction planet assembly 1024 is measured. In one embodiment, the actual tilt angle (γ) of the traction planet assembly 1024 can be determined by using a proximity sensor or other device adapted to provide an indication of the actual tilt angle tilt angle (γ) of the traction planet assemblies 1024. Next, the skew-based control process 2100 proceeds to a decision block 2106 where the measured tilt angle tilt angle (γ) is compared to the desired tilt angle tilt angle (γ) set point to thereby form a comparison value. If the measured tilt angle (γ) is not equal to the desired tilt angle (γ) set point, the skew-based control process 2100 returns to the block 2103. If the measured tilt angle (γ) is equal to the desired tilt angle (γ) set point, the skew-based control process 2100 proceeds to an end block 2107. The skew-based control process 2100 remains at the end block 2107 until a new tilt angle (γ) set point is received. In some embodiments, the skew-based control process 2100 is configured to operate in an open loop manner; in such a case, the blocks 2105 and 2106 are not included in the skew-based control process 2100.

[0134] Referring now to **Figure 29C**, in one embodiment a skew control process 2110 can be implemented on, for example, a microprocessor in communication with power electronics hardware of the CVT 1000. In some embodiments, the skew-based control process 2110 can be implemented on a microprocessor in communication with the CVT 12 or other CVT embodiments described herein. The skew-based control process 2110 begins at a block 2111. The skew-based control process 2110 then proceeds to a block 2112 where a desired output speed set point of the CVT 1000 is received. The skew-based control process 2110 continues to a block 2113 where a command signal for a skew actuator is determined. In one embodiment, the command signal is determined by a well-known PI control process. Next, the skew-based control process 2110 moves to an actuator subprocess 2114 where the command signal is applied to the skew actuator 2054, for example. Upon completion of the actuator subprocess 2114, the skew-based control process 2110 proceeds to a block 2115 where the output speed of the CVT 1000 is measured. In one embodiment, the output speed of the CVT 1000 can be determined by using a speed sensor configured to measure a speed indicative of the output speed of the CVT 1000. Next, the skew-based control process 2110 proceeds to a decision block 2116 where the measured output speed is compared to the desired output speed set point to thereby form a comparison value. If the measured output speed is not equal to the desired output speed set point, the skew-based control process 2110 returns to the block 2113. If the measured output speed is equal to the desired output speed set point, the skew-based control process 2110 proceeds to an end block 2117. The skew-based control process 2110 remains at the end block 2117 until a new output speed set point is received. In some embodiments, the skew-based control process 2110 is configured to operate in an open loop manner; in such a case, the blocks 2115 and 2116 are not included in the skew-based control process 2110.

[0135] Referring now to **Figure 29D**, in one embodiment a skew control process 2120 can be implemented on, for example, a microprocessor in communication with power electronics hardware of the CVT 1000. In some embodiments, the skew-based control process 2120 can be implemented on a microprocessor in communication with the CVT 12 or other CVT embodiments described herein. The skew-based control process 2120 begins at a block 2121. The skew-based control process 2120 then proceeds to a block 2122 where a desired input speed set point of the CVT 1000 is received. The skew-based control process 2120 continues to a block 2123 where a command signal for a skew actuator is determined. In one embodiment, the command signal is determined by a well-known PI control process. Next, the skew-based control process 2120 moves to an actuator subprocess 2124 where the command signal is applied to the skew actuator 2054, for example. Upon completion of the actuator subprocess 2124, the skew-based control process 2120 proceeds to a block 2125 where the input speed of the CVT 1000 is measured. In one embodiment, the input speed of the CVT 1000 can be determined by using a speed sensor configured to measure a speed indicative of the input speed of the CVT 1000. Next, the skew-based control process 2120 proceeds to a decision block 2126 where the measured input speed is compared to the desired input speed set point to thereby form a comparison value. If the measured input speed is not equal to the desired input speed set point, the skew-based control process 2120 returns to the block 2123. If the measured input speed is equal to the desired input speed set point, the skew-based control process 2120 proceeds to an end block 2127. The skew-based control process 2120 remains at the end block 2127 until a new output speed set point is received. In some embodiments, the skew-based control process 2120 is configured to operate in an open loop manner; in such a case, the blocks 2125 and 2126 are not included in the skew-based control process 2120.

[0136] Passing now to **Figures 30-33**, in one embodiment a CVT 3000 can include a first housing member 3002 coupled to a second housing member 3004. The first housing member 3002 can be provided on a first end with a flange 3006. The flange 3006 can facilitate the coupling of the CVT 3000 to, for example, an electric drive motor (not shown). In some embodiments, the CVT 3000 can couple to a crank shaft of an internal combustion engine (not shown). The CVT 3000 can include a skew actuator 3005 coupled to a skew driver 3007. The skew actuator 3005 and the skew driver 3007 can be adapted to facilitate an adjustment in the skew condition and consequently the operating condition of the CVT 3000. In some embodiments, the skew actuator 3005 can be in communication with a skew control system (not shown).

[0137] In one embodiment, the CVT 3000 is provided with a main shaft 3008 that can be configured to be substantially aligned with a longitudinal axis 3010 of the CVT 3000. The main shaft 3008 can couple to an input driver 3012 and to a planetary driver 3014. In one embodiment, the main shaft 3008 can be adapted to couple to certain components of a pump 3015. In one embodiment, the pump 3015 is a well known gearotor-type pump. In one instance, the pump 3015 includes an inner gear configured to be driven by the main shaft 3008. The pump 3015 can also include a housing configured to be substantially non-rotatable about the longitudinal axis 3010. The pump 3015 can be configured to provide lubrication to the CVT. In some embodiments, the pump 3015 can be configured to supply a pressurized hydraulic fluid to, for example, a control system on an aircraft. The planetary driver 3014 can be configured to couple to a planetary gear assembly 3016. In one embodiment, the planetary gear assembly 3016 can be a dual pinion planetary gear set having a sun gear, a set of planet gears, a carrier, and a ring gear. In some embodiments, the planetary driver 3014 can be coupled to the carrier of the planetary gear assembly 3016.

[0138] Still referring to Figures 30-33, in one embodiment the CVT 3000 is provided with a first traction ring 3018 coupled to the input driver 3012. The first traction ring 3018 is in contact with a variator assembly 3020. The CVT 3000 can be provided with a second traction ring 3022 in contact with a variator assembly 3020. The second traction ring 3022 can be coupled to an axial force generator assembly 3024. In one embodiment, the axial force generator assembly 3024 includes a number of rollers configured to cooperate with a number of ramps to produce axial force during operation of the CVT 3000. The axial force generator assembly 3024 can be coupled to a planetary sun driver 3026. The planetary sun driver 3026 can be coupled to the sun gear of the planetary gear assembly 3016. In one embodiment, the planetary gear assembly 3016 can be coupled to an output shaft 3028. In some embodiments, the output shaft 3028 is coupled to the ring gear of the planetary gear assembly 3016.

[0139] During operation of the CVT 3000, an input power can be supplied to the CVT 3000 via a coupling to the main shaft 3008. The main shaft 3008 can transfer power to the input driver 3012 and to the planetary driver 3014. The input driver 3012 can be configured to transfer power to the first traction ring 3018 to thereby deliver power to the variator assembly 3020. The variator assembly 3020 transfers power to the second traction ring 3022. The second traction ring 3022 transfers power to the planetary sun driver 3026. In one embodiment, the power delivered to the planetary gear assembly 3016 through the planetary driver 3014 and the planetary sun driver 3026 is transferred out of the CVT 3000 through the output shaft 3028.

[0140] Referring now to **Figures 34** and **35**, in one embodiment a variator assembly 3020 includes a number of traction planet assemblies 3030 arranged angularly about the longitudinal axis 3010. Each traction planet assembly 3030 is adapted to contact a traction sun 3032 at a radially inward location. The traction sun 3032 is operably coupled to a set of shift cams 3034. In one embodiment, the traction sun 3032 and the shift cams 3034 are adapted to translate axially along the longitudinal axis 3010 during operation of the CVT 3000. The shift cams 3034 can be configured to couple to each of the traction planet assemblies 3030. In one embodiment, the variator assembly 3020 is provided with a first carrier member 3036 and a second carrier member 3038. The first and second carrier members 3036 and 3038 are configured to support each of the traction planet assemblies 3030. In one embodiment, the second carrier member 3038 is configured to rotate with respect to the first carrier member 3036. The first and second carrier members 3036 and 3038 can be coupled to the skew driver 3007. The first and second carrier members 3036 and 3038 can be coupled to a first carrier cap 3040 and a second carrier cap 3042, respectively. The first and second carrier caps 3040 and 3042 are configured to couple to each of the traction planet assemblies 3030. The first and second carrier caps 3040 and 3042 can be attached to the first and second carrier members 3036 and 3038 with clips 3044.

[0141] Referring specifically now to Figure 35, in one embodiment the variator assembly 3020 is provided with a number of carrier inserts 3046. The carrier inserts 3046 can be adapted to attach to the first and second carrier members 3036 and 3038. Once assembled, the carrier inserts 3046 can contact certain components of the traction planet assemblies 3030. In one embodiment, the carrier inserts 3046 are made of steel and the first and second carrier members 3036, 3038 are made of aluminum. In some embodiments, the carrier inserts 3046 are integral to the first and second carrier members 3036, 3038.

[0142] Turning now to **Figures 36** and **37**, in one embodiment the traction planet assembly 3030 includes a substantially spherical traction planet 3048 having a central bore adapted to receive a planet axle 3050. The traction planet 3048 can be coupled to the planet axle 3050 with bearings 3052. The traction planet assembly 3030 can include a first leg 3054 coupled to a first end of the planet axle 3050. The traction planet assembly 3030 can include a second leg 3056 coupled to a second end of the planet axle 3050, wherein the second end of the planet axle is at a distal location from the first end. The first and second legs 3054 and 3056 can each be adapted to receive a reaction roller 3058. In one embodiment, the reaction roller 3058 is received in a slot 3060 provided in each leg 3054, 3056. In one embodiment, the first leg 3054 can be attached to the planet axle 3050 with a press fit or by other suitable rigid coupling method. The roller 3058A can be configured to rotate about the planet axle 3050. In some embodiments, the second leg 3056 can be configured to rotate with respect to the planet axle 3050. The roller 3058B can be attached to the planet axle 3050 with a press fit or by other suitable rigid coupling methods, to thereby axially retain the second leg 3056 on the planet axle 3050. The rollers 3058 are configured to couple to the carrier members 3036 and 3038. In one embodiment, each of the first and second legs 3054 and 3056 are provided with a shift reaction roller 3062. The shift reaction roller 3062 can be received in a slot 3064 formed in each of the first and second legs 3054, 3056. In one embodiment, the slot 3064 is substantially perpendicular to the slot 3060. The shift reaction roller 3062 can be adapted to receive a shift roller axle 3066. The shift roller axle 3066 can be received in a bore 3068. During operation of the CVT 3000, the shift reaction rollers 3062 couple to the shift cams 3034.

[0143] Referring still to Figures 36 and 37, in one embodiment the first and second legs 3054 and 3056 are provided with a bore 3070 adapted to receive the planet axle 3050. The bore 3070 can be substantially perpendicular to the slot 3060. The first and second legs 3054 and 3056 can be provided with a shoulder 3072. The shoulder 3072 can be substantially aligned with, and extend from, the bore 3070. In one embodiment, the shoulder 3072 is configured to cooperate with the bearings 3052. The first and second legs 3054 and 3056 can be provided with a reaction surface 3074. The reaction surface 3074 can have a curved profile when viewed in the plane of the page of Figure 37. The reaction surfaces 3074 can be adapted to slidingly engage the carrier caps 3040, 3042.

[0144] Passing now to **Figure 38**, in one embodiment the carrier insert 3046 can have a substantially u-shaped body 3076. The carrier insert 3046 can have a reaction surface 3078 formed on the interior of the u-shaped body 3076. The reaction surface 3078 is configured to contact the roller 3058 during operation of the CVT 3000. The carrier insert 3046 can have an exterior surface 3080. The exterior surface 3080 is adapted to attach to the first or second carrier member 3036 or 3038.

[0145] Referring now to **Figures 39** and **40**, in one embodiment the second carrier member 3038 can be a substantially bowl-shaped body 3082 having a central bore 3084. The bowl-shaped body 3082 can be provided with a number of radial slots 3086 arranged angularly about the central bore 3084. Each of the radial slots 3086 can have skew reaction surfaces 3088 configured to contact the rollers 3058. The second carrier member 3038 can be provided with a shoulder 3090 extending axially from the central bore 3084. The shoulder 3090 can be provided with a groove 3092 adapted to receive the clip 3044. The bowl shaped body 3082 can be provided with a substantially flat face 3094 formed about the outer periphery. The face 3094 can be configured to provide a sliding interface between the first and second carrier members 3036 and 3038. The second carrier member 3038 can be provided with a tab 3094 extending radially from the outer periphery of the bowl-shaped body 3082. The tab 3094 can be provided with an elongated hole 3095. The elongated hole 3095 can be configured to cooperate with the skew driver 3007 to provide a rotation of the second carrier member 3038 with respect to the first carrier member 3036 to thereby adjust the speed ratio during operation of the CVT 3000. In one embodiment, the first housing member 3002 is provided with a cavity 3096 (Figures 30 and 31) configured to surround the tab 3094 and facilitate the coupling of the first and second carrier members 3036 and 3038 to the skew driver 3007. In some embodiments, the first carrier member 3036 is substantially similar to the second carrier member 3038. The first carrier member 3036 can be provided with a bore 3098 (Figure 34). Upon assembly of the CVT 3000, the bore 3098 can be arranged to substantially align with the elongated hole 3095 and can be adapted to cooperate with the skew driver 3007.

[0146] Turning now to **Figures 41** and **42**, in one embodiment the skew driver 3007 can be a substantially cylindrical rod 3100 having a first end 3102 and a second end 3104. The first end 3102 can be configured to facilitate the coupling of the skew driver 3007 to the skew actuator 3005 (Figure 30). In some embodiments, the first end 3102 is provided with a set of threads adapted to couple to the skew actuator 3005. In other embodiments, the first end 3102 is provided with a spline configured to couple to the skew actuator 3005. The second end 3104 can be adapted to couple to the first carrier member 3036. In some embodiments, the second end 3104 is configured to rotate in the bore 3098 of the first carrier member 3036. The skew driver 3007 can be provided with an eccentric skew cam 3106 formed in proximity to the second end 3104. The eccentric skew cam 3106 can be arranged to have a center 3108 that is radially offset from a center 3110 of the cylindrical rod 3100. The eccentric skew cam 3106 can be configured to couple to the elongated hole 3095 of the second carrier member 3038 (Figure 39). The eccentric skew cam 3106 is configured to slidingly engage the elongated hole 3095.

[0147] During operation of the CVT 3000, the skew driver 3007 can be rotated by the skew actuator 3007. The rotation of the skew driver 3007 tends to motivate a rotation of the second carrier member 3038 with respect to the first carrier member 3036. The rotation of the second carrier member 3038 with respect to the first carrier member 3036 induces a skew condition on each of the traction planet assemblies 3030. The skew condition tends to motivate a tilt in the planet axles 3050 of the traction planet assemblies 3030. The tilting of the planet axles 3050 adjusts the speed ratio of the CVT 3000.

[0148] Passing now to **Figure 43**, in one embodiment a CVT 4000 can include a number of traction planets 4002 arranged angularly about a longitudinal axis. The CVT 4000 can be provided with a traction sun 4003 configured to contact each traction planet 4002 at a radially inward location. Each of the traction planets 4002 can be provided with a tiltable axis of rotation 4004 configured to be supported by first and second carrier members 4006 and 4008. In some embodiments, the first and second carrier members 4006 and 4008 are adapted to facilitate a skew condition on each of the traction planets 4002. In one embodiment, the first carrier member 4006 is substantially non-rotatable about the longitudinal axis of the CVT 4000. The CVT 4000 can include first and second traction rings 4010, 4012 in contact with each of the traction planets 4002. The first and second traction rings 4010, 4012 can be coupled to first and second axial force generators 4014, 4016, respectively. The first axial force generator 4014 can be coupled to an input driver 4018. The second axial force generator 4016 can be coupled to an output shaft 4020. In one embodiment, the input driver 4018 is coupled to a clutch 4022. The clutch 4022 can be adapted to receive an input power from, for example, an electric motor or other suitable prime mover.

[0149] During operation of the CVT 4000, the input power can be transferred from the clutch 4022 to the input driver 4018. The input driver 4018 delivers power to the first traction ring 4010 through the first axial force generator 4014. The first traction ring 4010 transfers power to each of the traction planets 4002. The traction planets 4002 transfer power to the second traction ring 4012. The power is delivered from the second traction ring 4012 to the output shaft 4020 via the second axial force generator 4016. In some embodiments, the output shaft 4020 is configured to supply power to a load 4024.

[0150] Turning now to **Figure 44**, in one embodiment a CVT 4100 can include a number of traction planets 4102 arranged angularly about a longitudinal axis. The CVT 4100 can be provided with a traction sun 4103 configured to contact each traction planet 4102 at a radially inward location. Each of the traction planets 4102 can be provided with a tiltable axis of rotation 4104. The traction planets 4102 can be adapted to couple to first and second carrier members 4106 and 4108 respectively. In one embodiment, the first and second carrier members 4106 and 4108 are configured to facilitate a skew condition on each of the traction planets 4102. In one embodiment, the first and second carrier members 4106 and 4108 are configured to rotate about the longitudinal axis of the CVT 4100. The CVT 4100 can include first and second traction rings 4110 and 4112, respectively. The first and second traction rings 4110 and 4112 can be coupled to first and second axial force generators 4114 and 4116, respectively. In one embodiment, the first axial force generator 4114 is configured to be substantially non-rotatable with respect to the longitudinal axis of the CVT 4100. The second axial force generator 4116 can be coupled to an output shaft 4118.

[0151] During operation of the CVT 4100, the first carrier member 4106 can be adapted to receive a power from an input shaft 4120. The first carrier member 4106 delivers the power to each of the traction planets 4102. The traction planets 4102 orbit the traction sun 4103 and transfer power to the second traction ring 4112. The power is transferred from the second traction 4112 to the output shaft via the second axial force generator 4116. The output shaft 4118 is adapted to supply power to a load 4122.

[0152] Passing now to **Figures 45-48**, in one embodiment a variator 4200 can include a traction sun assembly 4202 coupled to a number of traction planet subassemblies 4204. The variator 4200 can be configured to be used in, for example, the CVT 12, the CVT 1000, or the CVT 3000. Each of the traction planet subassemblies 4204 are operably coupled to a first carrier member 4206 and a second carrier member 4208. In some embodiments, a carrier retaining ring 4210 can attach to the first and second carrier members 4206 and 4208. The traction sun subassembly 4204 can include a traction sun 4212. The traction sun 4212 can have a central bore 4214 adapted to receive bearings 4216. The central bore 4214 can be provided with a shoulder 4218 and a c-clip groove 4220 to facilitate the coupling of the bearings 4216 to the central bore 4214. The traction sun 4212 can be provided with a number of lubricant passages 4222 extending radially outward from the central bore 4214. In one embodiment, an outer periphery of the traction sun 4214 is provided with first and second contact surfaces 4224A and 4224B extending from a valley 4226. The first and second contact surfaces 4224A and 4224B can contact each of the traction planet subassemblies 4204. The first and second contact surfaces 4224A and 4224B can extend from the valley 4226 at an angle 4228 when viewed in cross-section in the plane of Figure 48. In one embodiment, the angle 4228 is in the range of about 2 degrees to 45 degrees. In a preferred embodiment, the angle 4228 is about 5 degrees to 10 degrees. During operation of the variator 4200, the traction sun assembly 4202 is adapted to remain axially coupled to the traction planet subassemblies 4204 as the traction planet subassemblies 4204 tilt. In some embodiments, the bearings 4216 may be removed so that the sun assembly 4202 is no longer coupled to the central bore 4214, but remains radially coupled to the CVT 1000, for example, by contacting the traction planet assemblies 4204 through the contact surfaces 4224.

[0153] Turning now to **Figures 49-51**, in one embodiment a gear 5000 can be coupled to a first carrier member 5002 and to a second carrier member 5004. The gear 5000 can facilitate a rotation about a longitudinal axis between the first and second carrier members 5002, 5004. The gear 5000 can be provided with a shaft 5006. The shaft 5006 can extend radially outward from the first and second carrier members 5002, 5004. The shaft 5006 can be configured to couple to a skew actuator (not shown). In some embodiments, the gear 5000 can be a conical gear and the first and second carrier member 5002, 5004 can be adapted to accommodate the conical gear appropriately. During operation, the skew actuator can transmit a rotation to the shaft 5006 to thereby turn the gear 5000. The turning of the gear 5000 tends to rotate the first carrier member 5002 in a first rotational direction and tends to rotate the second carrier member 5004 in a second rotational direction substantially opposite to that of the first rotational direction.

[0154] Referring specifically now to Figures 50 and 51, in one embodiment a skew driver 5010 can be coupled to a first carrier member 5012 and to a second carrier member 5014. The first and second carrier members 5012, 5014 can be substantially similar to the first and second carrier members 5002, 5004. The first carrier member 5012 can be provided with threads to engage the skew driver 5010 at a first threaded interface 5016. The second carrier member 5014 can be provided with threads to engage to the skew driver 5010 at a second threaded interface 5018. The first threaded interface 5018 is typically a right-handed thread, while the second threaded interface 5018 is a left-handed thread. In one embodiment, the skew driver 5010 can be coupled to a skew actuator (not shown). In some embodiments, the skew driver 5010 is positioned to be tangent to the first and second carrier members 5012, 5014. During operation, the skew driver 5010 can be rotated to thereby induce a relative rotation between the first and second carrier members 5012, 5014. The threaded interfaces 5016 and 5018 can be adapted to accommodate a small radial displacement to facilitate the rotation of the first and second carrier member 5012, 5014 with respect to each other.

[0155] Referring specifically now to Figure 52, in one embodiment a gear 5020 can be coupled to a first carrier member 5022 and to a second carrier member 5024. For clarity, the gear 5020 is shown in Figure 52 without well-known gear teeth. The gear 5020 can facilitate a rotation about a longitudinal axis between the first and second carrier members 5022, 5024. The gear 5020 can be provided with a shaft 5026. The shaft 5026 can be configured to couple to a skew actuator (not shown). In one embodiment, the shaft 5026 extends axially from the gear 5020. The first carrier member 5022 can be provided with an engagement extension 5028 adapted to contact the gear 5020. During operation, the skew actuator can transmit a rotation to the shaft 5026 to thereby turn the gear 5020. The turning of the gear 5020 tends to rotate the first carrier member 5022 in a first rotational direction and tends to rotate the second carrier member 5024 is a second rotational direction substantially opposite to that of the first rotational direction.

[0156] It should be noted that the description above has provided dimensions for certain components or subassemblies. The mentioned dimensions, or ranges of dimensions, are provided in order to comply as best as possible with certain legal requirements, such as best mode. However, the scope of the inventions described herein are to be determined solely by the language of the claims, and consequently, none of the mentioned dimensions is to be considered limiting on the inventive embodiments, except in so far as anyone claim makes a specified dimension, or range of thereof, a feature of the claim.

[0157] The foregoing description details certain embodiments of the invention. It will be appreciated, however, that no matter how detailed the foregoing appears in text, the invention can be practiced in many ways. As is also stated above, it should be noted that the use of particular terminology when describing certain features or aspects of the invention should not be taken to imply that the terminology is being re-defined herein to be restricted to including any specific characteristics of the features or aspects of the invention with which that terminology is associated.

WHAT WE CLAIM IS:

1. A continuously variable accessory drive (CVAD) comprising:

a continuously variable transmission (CVT) coupled to an accessory device,

the continuously variable transmission having a plurality of traction planets, each traction planet adapted to rotate about a tiltable axis; and

a skew actuator operably coupled to the CVT, the skew actuator adapted to apply a skew condition to the CVT to tilt the axes of the traction planets.

2. The CVAD of Claim 1, wherein the CVT comprises a first carrier member coupled to a second carrier member, the first and second carrier members operably coupled to each traction planet, wherein the first carrier member is configured to rotate relative to the second carrier member about a longitudinal axis of the CVT.

3. The CVAD of Claim 2, wherein the first carrier member comprises a plurality of radially offset slots formed angularly about the longitudinal axis.

4. The CVAD of Claim 1, further comprising an output arranged along a longitudinal axis of the CVT, the output configured to couple the CVAD to the accessory device.

5. The CVAD of Claim 4, further comprising an alternator coupled to the output.

6. The CVAD of Claim 4, further comprising a pump coupled to the output.

7. The CVAD of Claim 1, wherein the CVT is configured to receive an input power from a pulley driven by a prime mover.

8. A continuously variable accessory drive (CVAD) comprising:

a plurality of traction planets arranged angularly about a longitudinal axis of the CVAD, the traction planets configured to transfer a power to an accessory device;

a plurality of planet axles, each planet axle operably coupled to each traction planet, each planet axle defining a tiltable axis of rotation for each traction planet, each planet axle configured for angular displacement in a plane perpendicular to the longitudinal axis, each planet axle configured for angular displacement in a plane parallel to the longitudinal axis;

a first carrier member operably coupled to a first end of each planet axle, the first carrier member mounted about the longitudinal axis;

a second carrier member operably coupled to a second end of each planet axle, the second carrier member mounted about the longitudinal axis; and

wherein the first and second carrier members are configured to rotate relative to each other about the longitudinal axis.

9. The CVAD of Claim 8, further comprising a skew actuator operably coupled to at least one of the first and second carrier members.

10. The CVAD of Claim 8, further comprising a skew driver coupled to the first and second carrier members, the skew driver configured to apply relative rotation between the first and second carrier members.

11. The CVAD of Claim 10, wherein the skew driver comprises an eccentric skew cam adapted to couple to at least one of the first and second carrier members.

12. The CVAD of Claim 8, further comprising an output device arranged along the longitudinal axis, the output device configured to transfer power from the CVAD to an accessory device.

13. The CVAD of Claim 8, further comprising a pulley configured to transfer an input power to each of the traction planets.

14. The CVAD of Claim 12, wherein the accessory device is an alternator.

15. The CVAD of Claim 12, wherein the accessory device is a pump.

16. A continuously variable accessory drive (CVAD) comprising:

a rotatable input coaxial with a longitudinal axis of the CVAD;

a variator coaxial with the longitudinal axis and coupled to the rotatable input, the variator having a rotatable output;

a planetary gear assembly coupled to the rotatable output, the planetary gear assembly configured to power an accessory device;

wherein the variator comprises:

a plurality of traction planets arranged angularly about the longitudinal axis

a first carrier member operably coupled to each of the traction planets;

a second carrier member operably coupled to each of the traction planets; and

wherein the second carrier member is configured to rotate relative to the first carrier member to thereby apply a skew condition on each of the planet axles.

17. The CVAD of Claim 16, further comprising a pump operably coupled, directly to the rotatable input.

18. The CVAD of Claim 16, further comprising first and second carrier caps coupled to the first and second carrier members, respectively.

19. The CVAD of Claim 18, wherein each of the traction planets comprise at least one leg, the leg configured to slidingly engage at least one of the first or second carrier caps.

20. The CVAD of Claim 16, further comprising a plurality of carrier inserts coupled to the first and second carrier members, the carrier inserts adapted to operably couple to each of the traction planets.

21. A continuously variable accessory drive (CVAD) comprising:

a plurality of traction planets arranged angularly about a longitudinal axis of the CVAD, the traction planets configured to transfer a power to an accessory device;

a plurality of planet axles, each planet axle operably coupled to each traction planet, each planet axle defining a tiltable axis of rotation for each traction planet, each planet axle configured for angular displacement in a plane perpendicular to the longitudinal axis, each planet axle configured for angular displacement in a plane parallel to the longitudinal axis;

a first carrier member arranged coaxial about the longitudinal axis, the first carrier member operably coupled to each traction planet, the first carrier member having a plurality of radially offset slots arranged angularly about a center of the first carrier member, each of the radially offset slots having a linear offset from a centerline of the carrier member;

a second carrier member arranged coaxial about the longitudinal axis, the second carrier member having a plurality of radial slots, the radial slots arranged angularly about a center of the second carrier member, each of the radial slots substantially radially aligned with the center of the second carrier member;

a skew actuator operably coupled to at least one of the first and second carrier members, the actuator configured to impart a relative rotation between the first and second carrier members.

22. The CVAD of Claim 21, further comprising a traction sun located radially inward of, and in contact with, each of the traction planets, the traction sun substantially fixed axially with respect to the longitudinal axis.

23. The CVAD of Claim 21, further comprising a traction sun located radially inward of, and in contact with, each of the traction planets, the traction sun having an outer periphery provided with a first and a second contact surface, the first and second contact surfaces configured to contact each of the traction planets.

24. The CVAD of Claim 21, further comprising a clevis coupled to at least one of the first and second carrier members, the clevis coupled to the skew actuator.

25. A method of manufacturing a continuously variable accessory drive (CVAD), the method comprising the steps of:

providing a plurality of traction planets;

providing each of the traction planets with a planet axle, each traction planet configured to rotate about a respective planet axle;

providing a first carrier member configured to engage a first end of each of the planet axles, the first carrier member mounted along a longitudinal axis of the CVAD;

providing a second carrier member configured to engage a second end of each of the planet axles, the second carrier member mounted coaxially with the first carrier member; and

arranging the first carrier member relative to the second carrier member such that during operation of the CVAD the first carrier member can be rotated relative to the second carrier member about the longitudinal axis to thereby adjust an operating condition of an accessory device.

26. The method of Claim 25, wherein arranging the first carrier member relative to the second carrier member comprises the step of operably coupling a carrier retaining ring to the first and second carrier members.

27. The method of Claim 25, further comprising the step of providing a main shaft arranged along the longitudinal axis, the main shaft configured to transfer a power to an accessory device.

28. The method of Claim 27, further comprising the step of operably coupling an alternator to the main shaft.

29. The method of Claim 27, further comprising the step of operably coupling a pump to the main shaft.

30. A variator, the variator comprising:

a plurality of traction planets arranged angularly about a longitudinal axis;

a first carrier member arranged coaxial about the longitudinal axis, the first carrier member operably coupled to each traction planet, the first carrier member having a plurality of radially offset slots arranged angularly about a center of the first carrier member, each of the radially offset slots having a linear offset from a centerline of the carrier member;

a second carrier member arranged coaxial about the longitudinal axis, the second carrier member having a plurality of radial slots, the radial slots arranged angularly about a center of the second carrier member, each of the radial slots substantially radially aligned with the center of the second carrier member; and

a traction sun assembly radially inward of, and in contact with, each traction planet, the traction sun assembly in contact with the first and second carrier members, the traction sun assembly substantially fixed along the longitudinal axis.

31. The variator of Claim 30, further comprising a planet axle coupled to each of the traction planets, the planet axle having a first and second end, the first and second ends configured to receive a shift reaction ball.

32. The variator of Claim 30, further comprising a carrier retaining ring coupled to the first and second carrier members, the carrier retaining ring substantially non-rotatable with respect to the longitudinal axis.

33. The variator of Claim 30, further comprising first and second traction rings in contact with each of the traction planets, the first traction ring configured to receive an input power, the second traction ring configured to transfer the input power to an accessory device.

34. The variator of Claim 33, further comprising a main shaft arranged along the longitudinal axis, the main shaft operably coupled to the second traction ring.

35. The variator of Claim 33, wherein the plurality of traction planets are configured to transfer a power to an accessory device.

36. A method of assembling a device for modulating power to an accessory device, the method comprising the steps of:

providing a continuously variable transmission (CVT) having a plurality of traction planets arranged angularly about a longitudinal axis, the CVT having a skew-based control system adapted to apply a skew condition to each of the traction planets; and

operably coupling the CVT to the accessory device.

37. The method of Claim 36, wherein providing a CVT comprises providing a skew actuator coupled to the CVT.

38. The method of Claim 37, wherein operably coupling the CVT to the accessory device comprises coupling a main shaft of the CVT to a driven shaft of the accessory device.

39. The method of Claim 37, further comprising the step of operably coupling the CVT to a prime mover.

40. The method of Claim 37, further comprising the step of configuring the skew actuator to communicate with a skew controller, wherein the skew controller is adapted to control a speed ratio of the CVT.

41. The method of Claim 37, further comprising the step of configuring the skew actuator to communicate with a skew controller, wherein the skew controller is adapted to control the speed of the accessory device.

42. A variator comprising:

a plurality of traction planets arranged angularly about a longitudinal axis;

a first carrier member arranged coaxial about the longitudinal axis, the first carrier member operably coupled to each traction planet, the first carrier member having a plurality of radially offset slots arranged angularly about a center of the first carrier member, each of the radially offset slots having a linear offset from a centerline of the carrier member;

a second carrier member arranged coaxial about the longitudinal axis, the second carrier member having a plurality of radial slots, the radial slots arranged angularly about a center of the second carrier member, each of the radial slots substantially radially aligned with the center of the second carrier member; and

a traction sun located radially inward of, and in contact with, each traction planet, the traction sun having an outer periphery provided with a first and a second contact surface, the first and second contact surfaces configured to contact each of the traction planets.

43. The variator of Claim 42, wherein the first and second contact surfaces extend from a valley at an angle in the range of 2 degrees to 45 degrees.

44. The variator of Claim 43, wherein the angle is in the range of 5 degrees to 10 degrees.

45. The variator of Claim 42, wherein the plurality of traction planets are configured to transfer a power to an accessory device.

46. A variator comprising:

a plurality of traction planets arranged angularly about a longitudinal axis;

a planet axle operably coupled to each traction planet, the planet axle configured to provide a tiltable axis of rotation for each traction planet;

a first carrier member arranged coaxially about the longitudinal axis, the first carrier member operably coupled to a first end of the planet axle;

a second carrier member arranged coaxially about the longitudinal axis, the second carrier member operably coupled to a second end of the planet axle;

a carrier retaining ring coupled to the first and second carrier members, the carrier retaining ring substantially non-rotatable about the longitudinal axis, the carrier retaining ring configured to axially couple the first and second carrier members; and wherein the first carrier member is configured to rotate with respect to the second carrier member to thereby apply a skew condition on each of the planet axles.

47. The variator of Claim 46, further comprising a clevis coupled to the first and/or the second carrier member, the clevis extending radially outward from an opening provided in the carrier retaining ring.

48. The variator of Claim 46, further comprising an output arranged along the longitudinal axis, the output configured to transfer power to an accessory device.

49. The variator of Claim 46, further comprising an accessory device operatively coupled to the output.

50. A variator having a plurality of traction planets arranged angularly about a longitudinal axis, the variator comprising:

a first carrier member coaxial with the longitudinal axis;

a second carrier member coaxial with the longitudinal axis; and

a skew driver coupled to the first and second carrier members, the skew driver adapted to rotate the first carrier member in a first rotational direction about the longitudinal axis, the skew driver adapted to rotate the second carrier member in a second rotational direction about the longitudinal axis, the first rotational direction substantially opposite to the second rotational direction.

51. The variator of Claim 50, wherein the skew driver comprises a gear coupled to the first and second carrier members.

52. The variator of Claim 51, further comprising a shaft coupled to the gear, the shaft extending radially outward from the gear (with reference to the longitudinal axis).

53. The variator of Claim 51, further comprising a shaft coupled to the gear, the shaft extending axially from the gear (with reference to the longitudinal axis).

54. The variator of Claim 50, wherein the skew driver comprises a threaded portion in contact with the first carrier member.

55. A method of adjusting a speed ratio of a continuously variable accessory drive (CVAD) having a plurality of traction planets, each traction planet having a tiltable

axis of rotation, the CVAD having a carrier member operably coupled to each of the traction planets, the method comprising the steps of:

determining a set point for an angular displacement of the carrier member, the set point for the angular displacement of the carrier member based at least in part on a set point for the speed ratio;

rotating the carrier member to the set point for the angular displacement of the carrier member, wherein rotating the carrier member induces a skew condition on each tiltable axis of rotation, the carrier member configured to adjust the skew condition as each tiltable axis of rotation tilts; and

wherein rotating the carrier member comprises actuating a skew actuator.

56. The method of Claim 55, further comprising the step of measuring the actual speed ratio of the CVAD.

57. The method of Claim 56, further comprising the step of comparing the actual speed ratio of the CVAD to the speed ratio setpoint to thereby generate a comparison value.

58. A method of adjusting a speed ratio of a continuously variable accessory drive (CVAD) having a plurality of traction planets, each traction planet having a tiltable axis of rotation, the CVAD having a skew actuator operably coupled to each of the traction planets, the method comprising the steps of:

determining a skew actuator command signal, said command signal based at least in part on a set point for the tilt angle; and

applying the skew actuator command signal to the skew actuator to thereby adjust the skew condition of the traction planets.

59. The method of Claim 58, further comprising the step of measuring the actual tilt angle of the traction planets.

60. A method of adjusting a speed ratio of a continuously variable accessory drive (CVAD) having a plurality of traction planets, each traction planet having a tiltable axis of rotation, the CVAD having a skew actuator operably coupled to each of the traction planets, the method comprising the steps of:

determining a skew actuator command signal, said command signal based at least in part on a set point for the desired speed; and applying the skew actuator command signal to the skew actuator to thereby adjust the skew condition of the traction planets.

61. The method of Claim 60, wherein the desired speed is indicative of an output speed of the CVAD.

62. The method of Claim 60, wherein the desired speed is indicative of an input speed of the CVAD.

63. A traction planet assembly comprising:

a traction planet having a central bore;

a planet axle arranged in the central bore, the planet axle having a first end and a second end;

a first leg coupled to the first end of the planet axle, the first leg substantially non-rotatable with respect to the planet axle; and

a second leg coupled to the second end of the planet axle, the second leg substantially rotatable with respect to the planet axle.

64. The traction planet of Claim 63, further comprising a roller coupled to the planet axle, wherein the roller is configured to be received in a slot of the second leg to thereby axially retain the second leg on the planet axle.

65. A traction planet assembly comprising:

a traction planet having a central bore;

a planet axle arranged in the central bore, the planet axle having a first end and a second end, the first and second ends provided with inner bores;

a shift reaction ball received in each of the inner bores;

a first leg coupled to the first end of the planet axle;

a second leg coupled to the second end of the planet axle; and

wherein the first and second legs are provided with tapered sides.

66. The traction planet assembly of Claim 65, further comprising a skew reaction roller coupled to each end of the planet axle.

67. A traction sun assembly for a continuously variable transmission (CVT) having a plurality of traction planet assemblies, the traction sun assembly comprising:

a traction sun coaxial with a longitudinal axis of the CVT, the traction sun radially inward of, and in contact with, each of the traction planet assemblies;

a shift cam operably coupled to the traction sun; and

a plurality of anti-rotation inserts attached to the shift cam, the anti-rotation inserts arranged to substantially flank each traction planet assembly.

68. The traction sun assembly of Claim 67, wherein the anti-rotation inserts are configured to rotationally constrain the shift cam during operation of the CVT.

69. A carrier member for a continuously variable transmission (CVT) having a plurality of traction planets, the carrier member comprising:

a substantially bowl-shaped body having a central bore; and

a plurality of radially offset slots arranged angularly about the central bore, each of the radially offset slots having a linear offset from a centerline of the bowl-shaped body.

70. The carrier member of Claim 69, wherein each of the radially offset slots have a curved profile.

71. A skew actuator for a continuously variable transmission (CVT) having a skew control system, the skew actuator comprising:

a hydraulic piston coupled to the CVT;

a hydraulic control valve in fluid communication with the hydraulic piston; and

a spool actuator coupled to the hydraulic control valve, the spool actuator configured to adjust the hydraulic control valve based at least in part on a desired skew condition of the CVT.

72. The skew actuator of Claim 71, wherein the hydraulic control valve comprising a housing and a spool, the housing configured to translate with respect to the spool.

73. A skew control system for a continuously variable accessory drive (CVAD) having a plurality of traction planets, the skew control system comprising:

a sensor configured to receive data from a CVAD;

a skew actuator configured to communicate with a control module, the skew actuator further configured to apply a skew condition to each of the traction planets in a CVAD;

a skew controller in communication with the control module, the skew controller configured to determine a skew actuator command signal based at least in part on a signal from the sensor; and

wherein the skew actuator command signal is configured to control an output speed of a CVAD.

74. The skew control system of Claim 73, wherein the sensor is configured to communicate with an accessory device.

75. The skew control system of Claim 73, wherein the skew actuator comprises a servo motor.

76. The skew control system of Claim 73, wherein the skew actuator comprises a hydraulic control valve.

77. The skew control system of Claim 73, wherein the skew actuator comprises a lever.

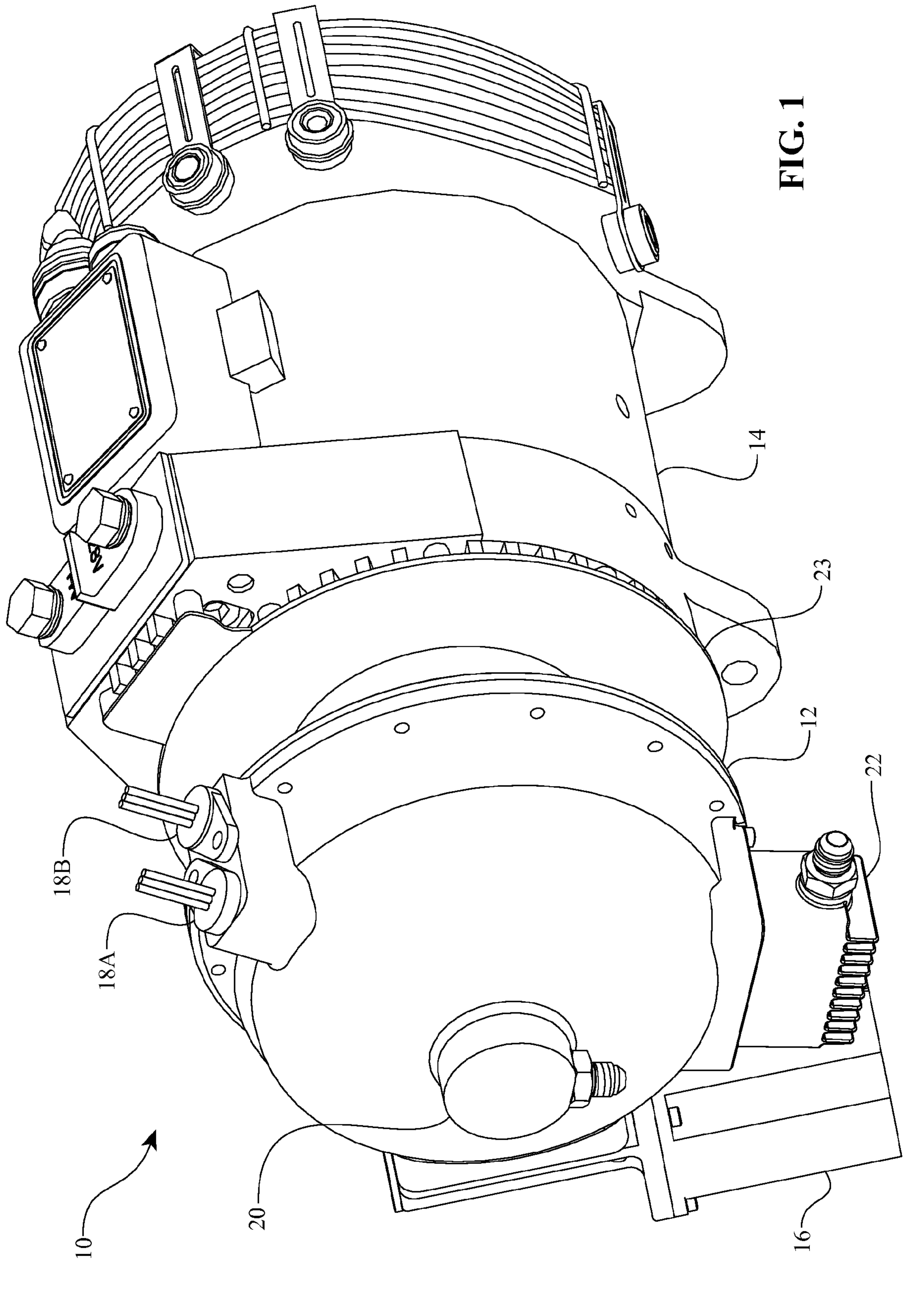


FIG. 1

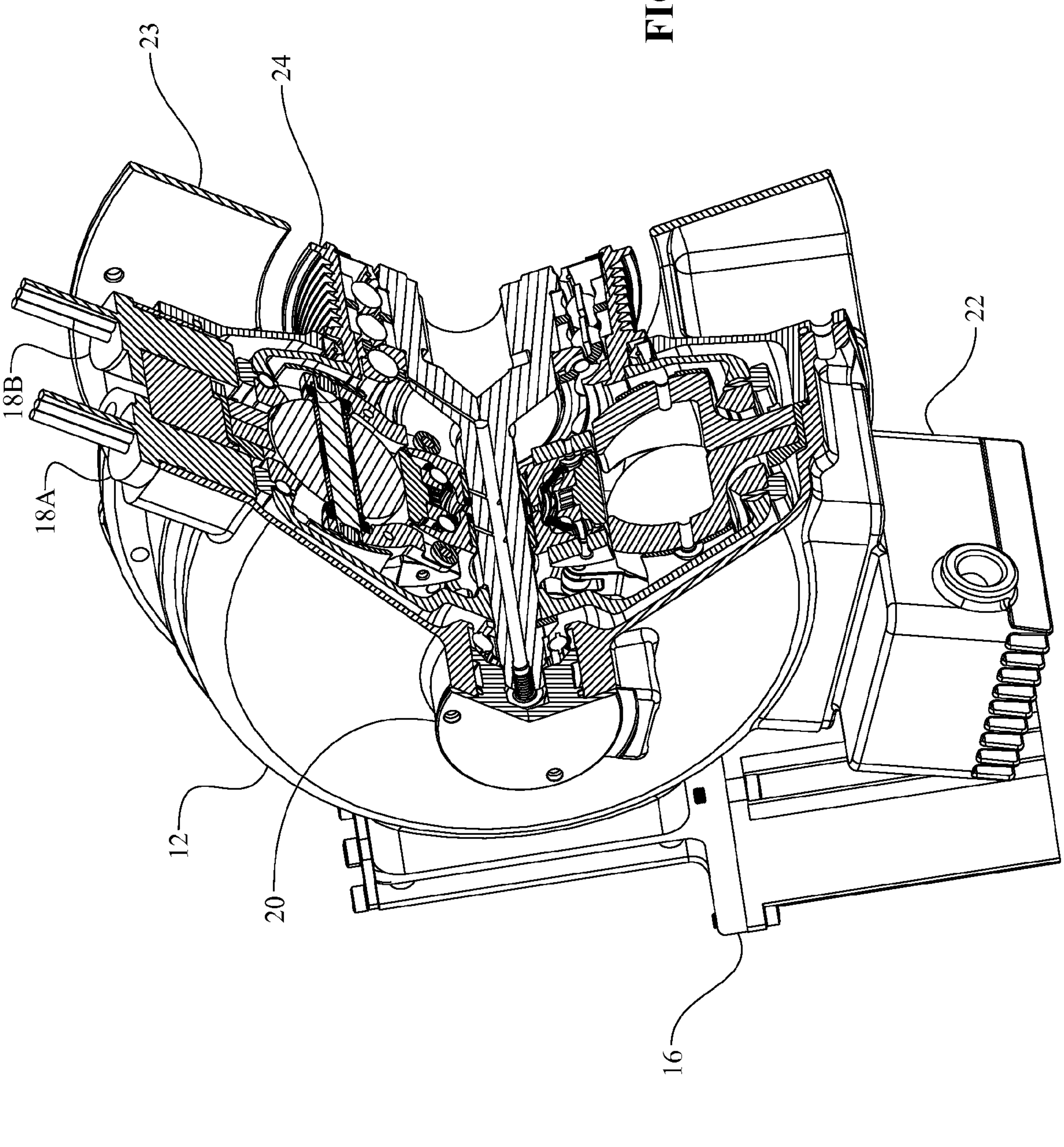


FIG. 2

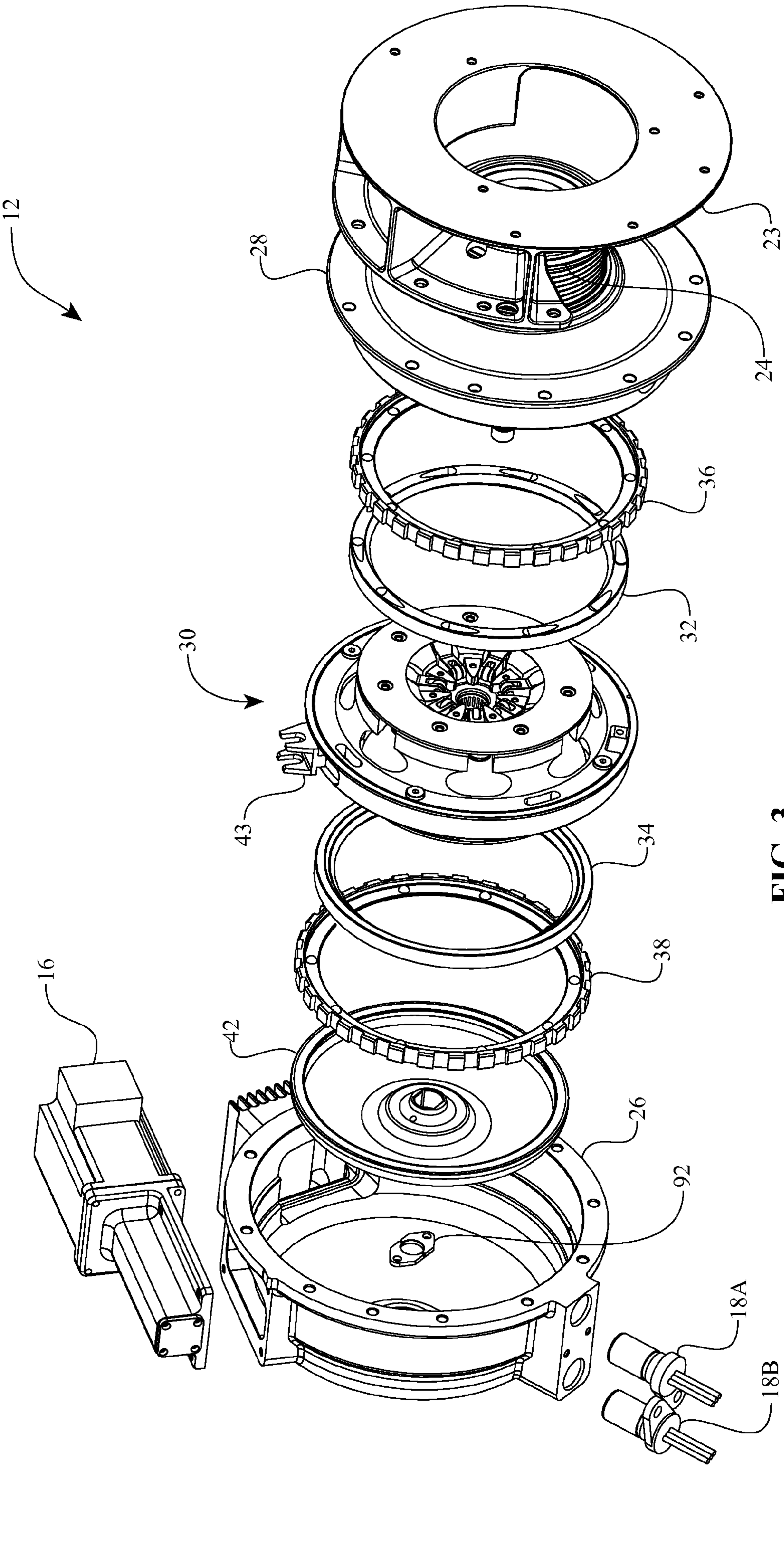


FIG. 3

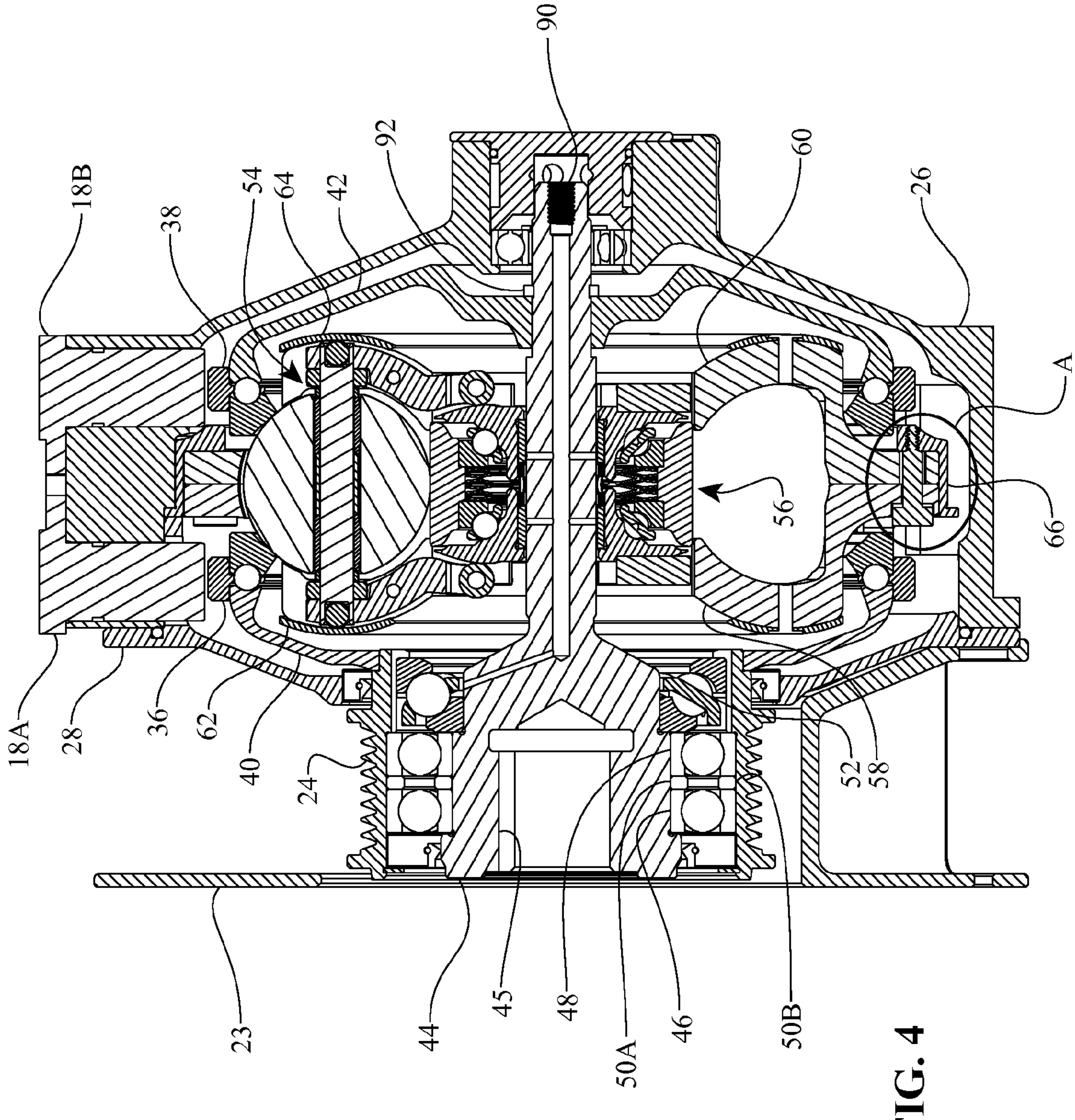

90
92
60
26
18B
38
54
64
42
A
56
66
18A
28
36
62
40
24
52
58
23
44
45
48
50A
46
50B

FIG. 4

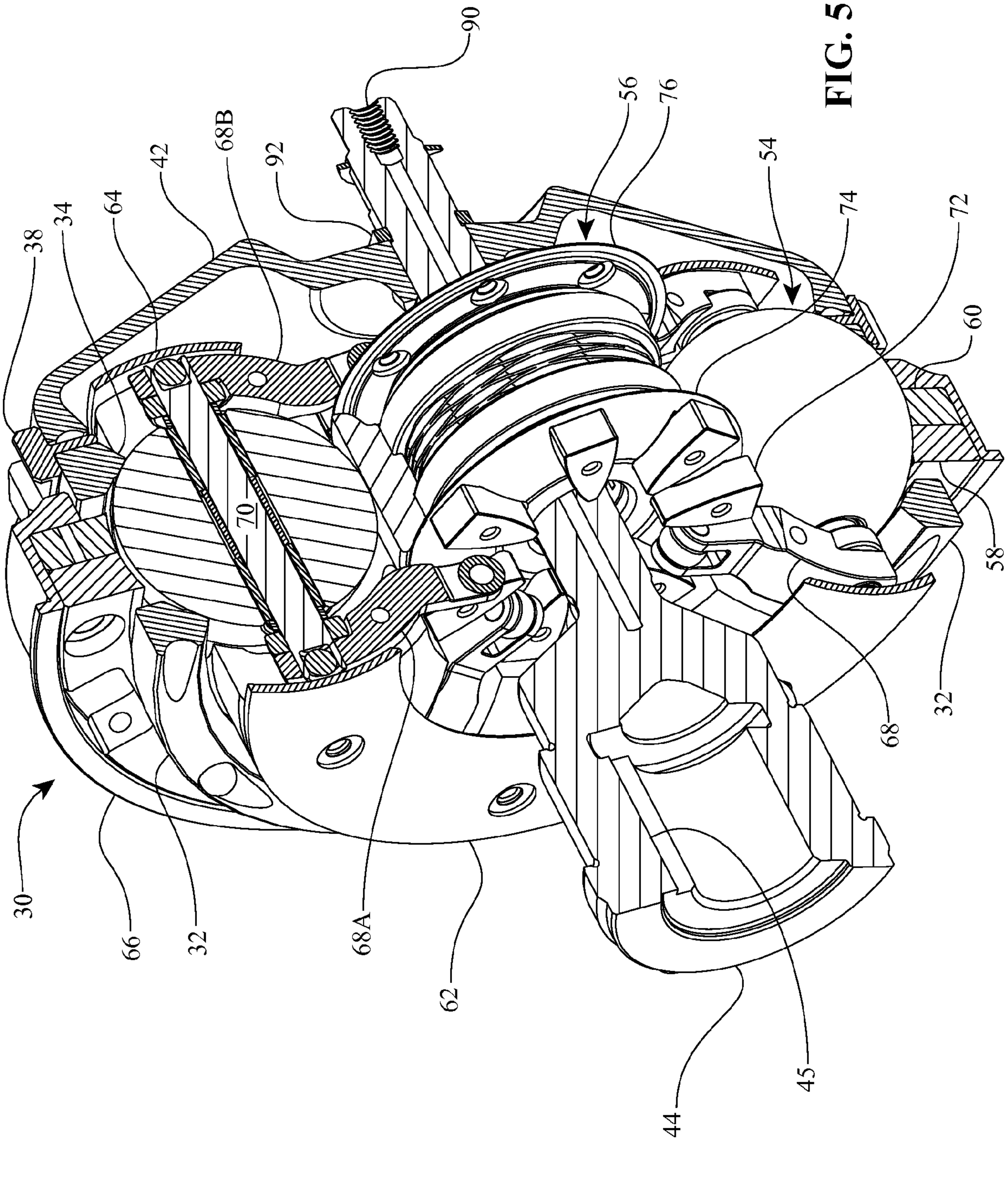

90
56
76
54
74
72
60
58
32
68
45
44
62
68A
32
66
30
70
68B
92
42
64
34
38

FIG. 5

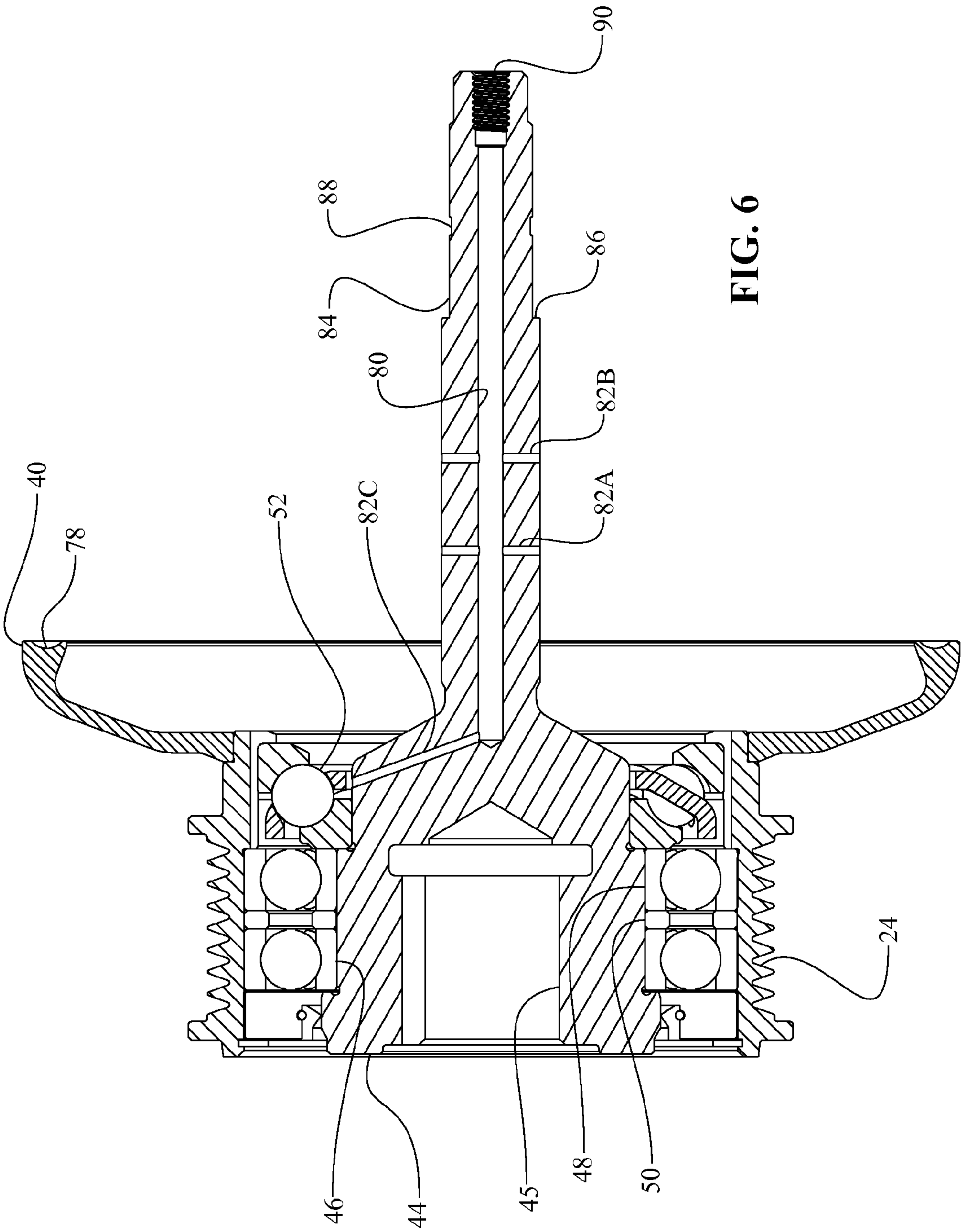


FIG. 6

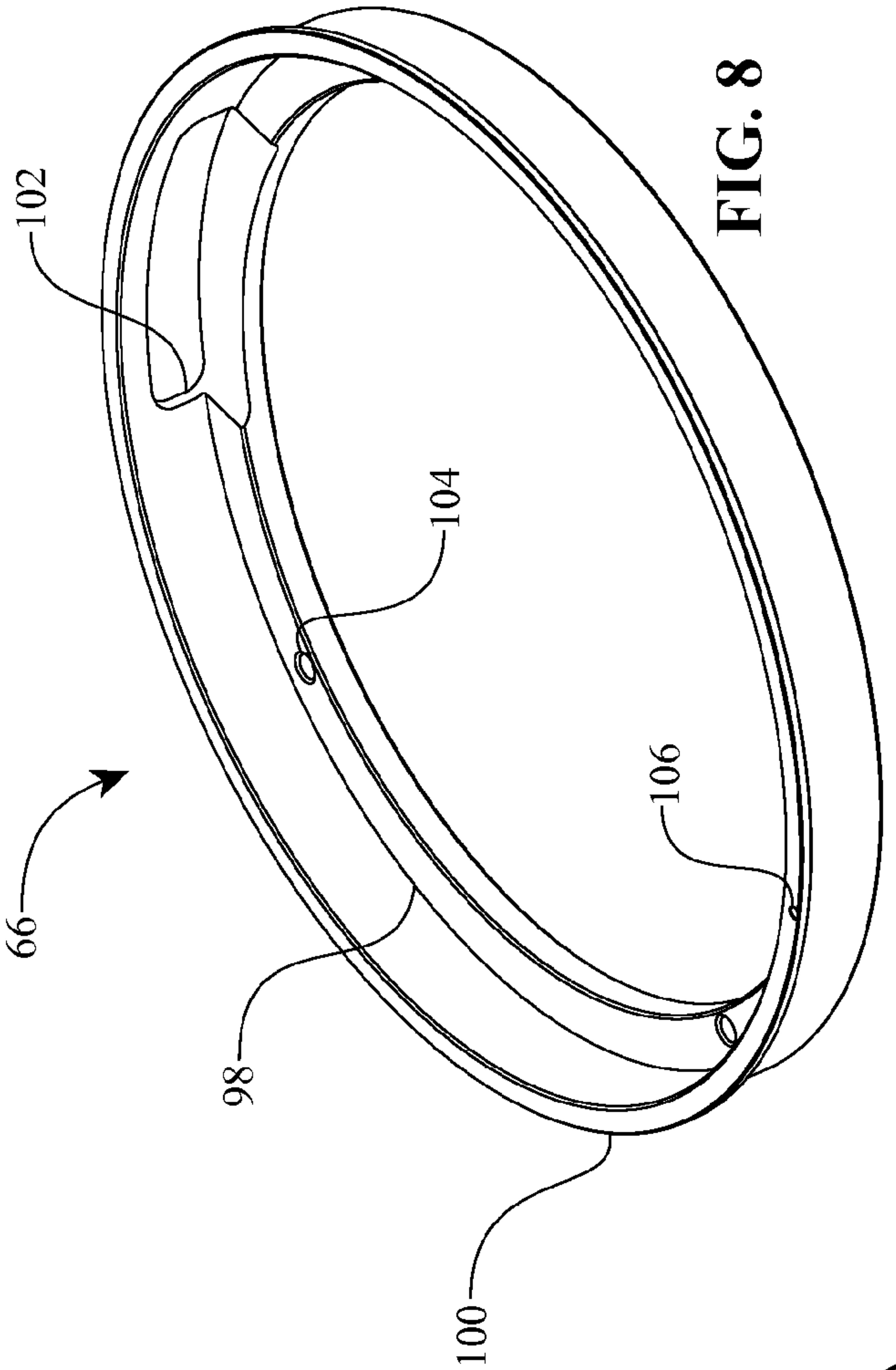


FIG. 8

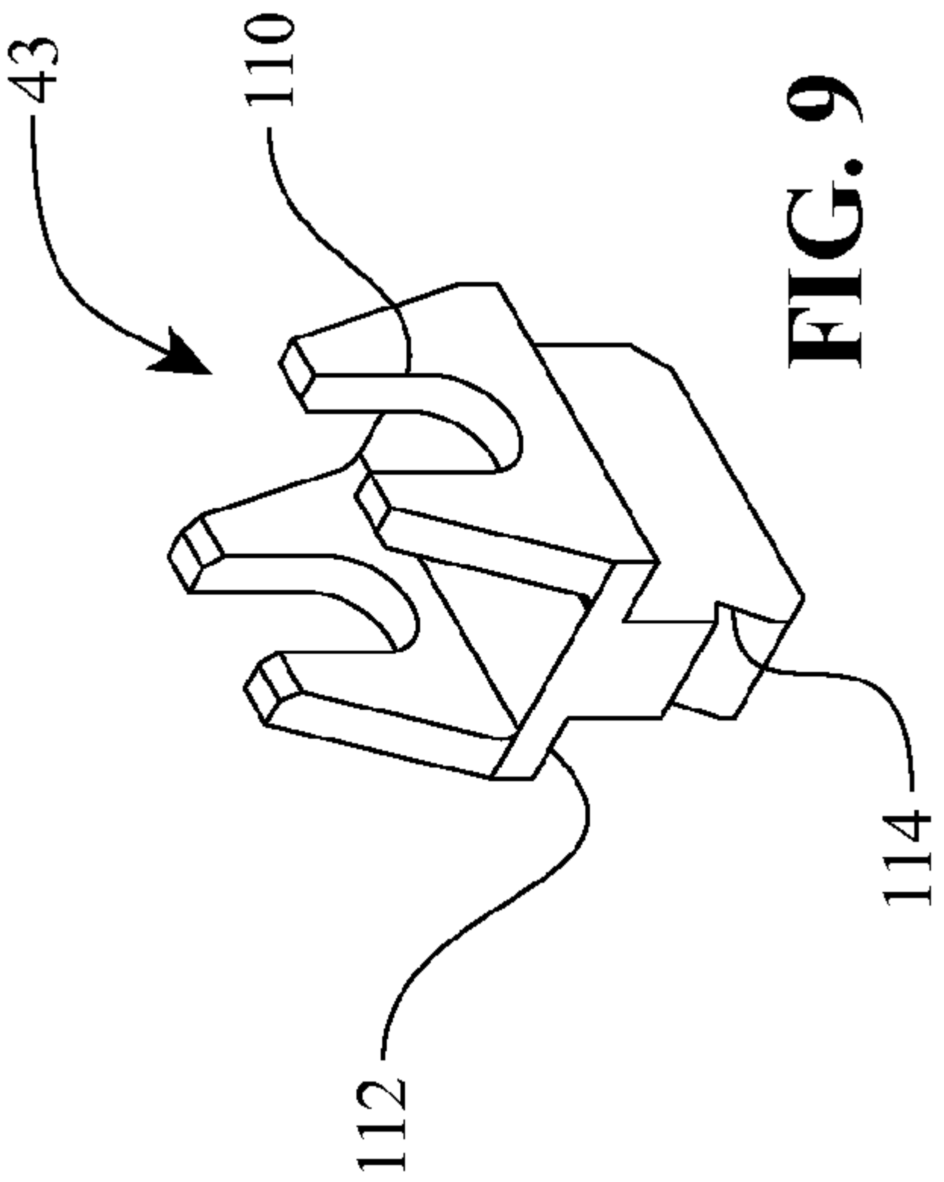


FIG. 9

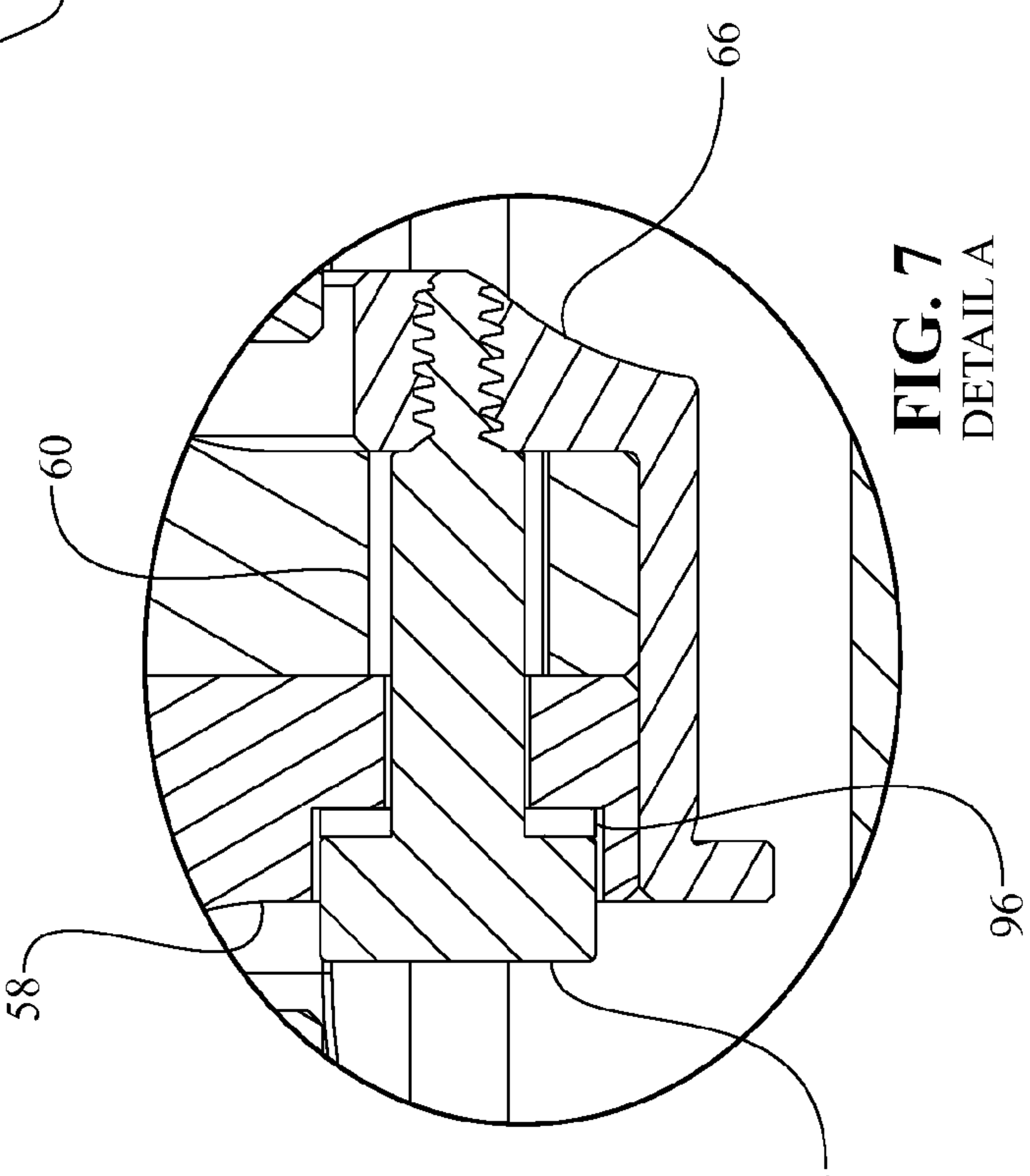


FIG. 7
DETAIL A

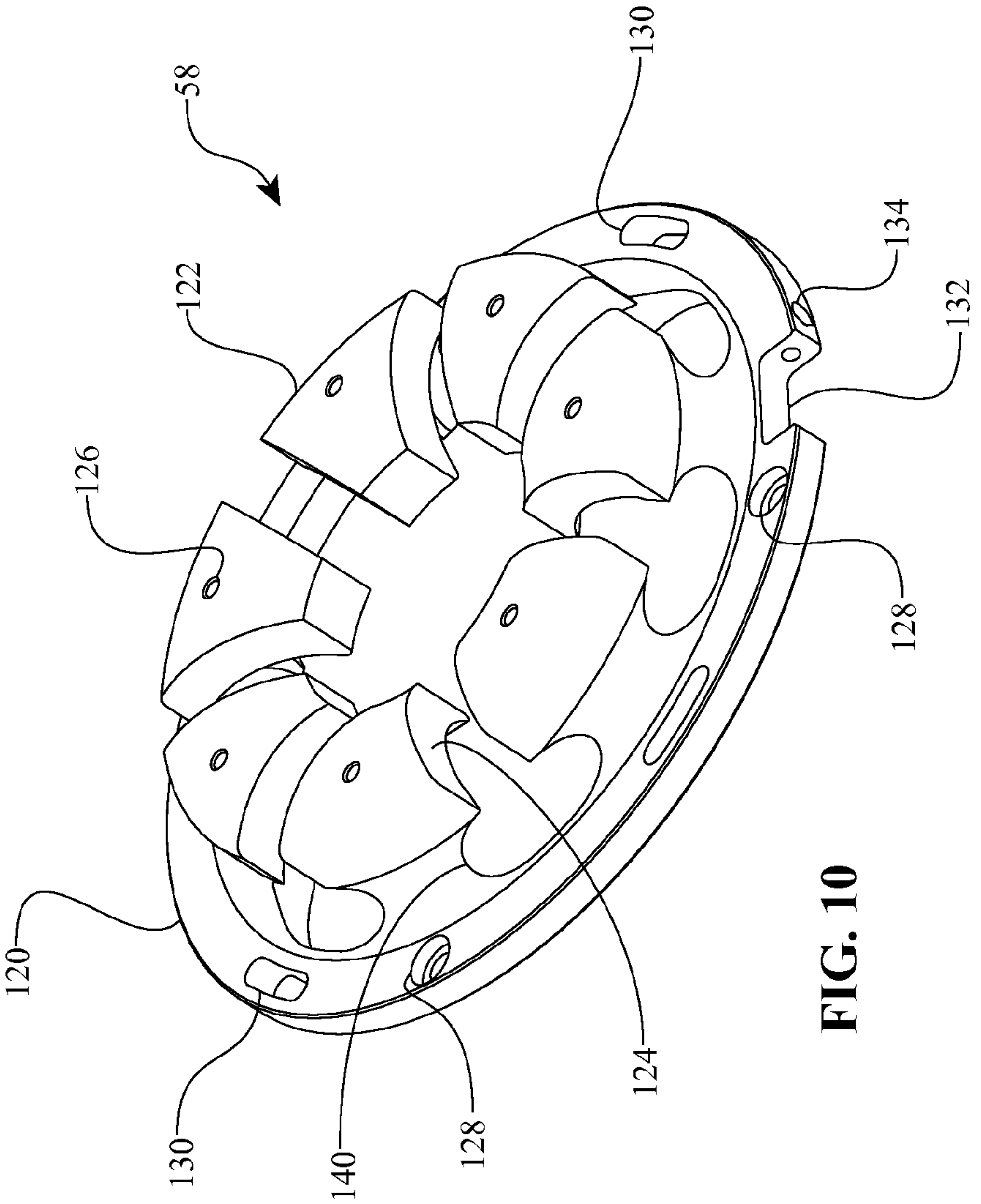


FIG. 10

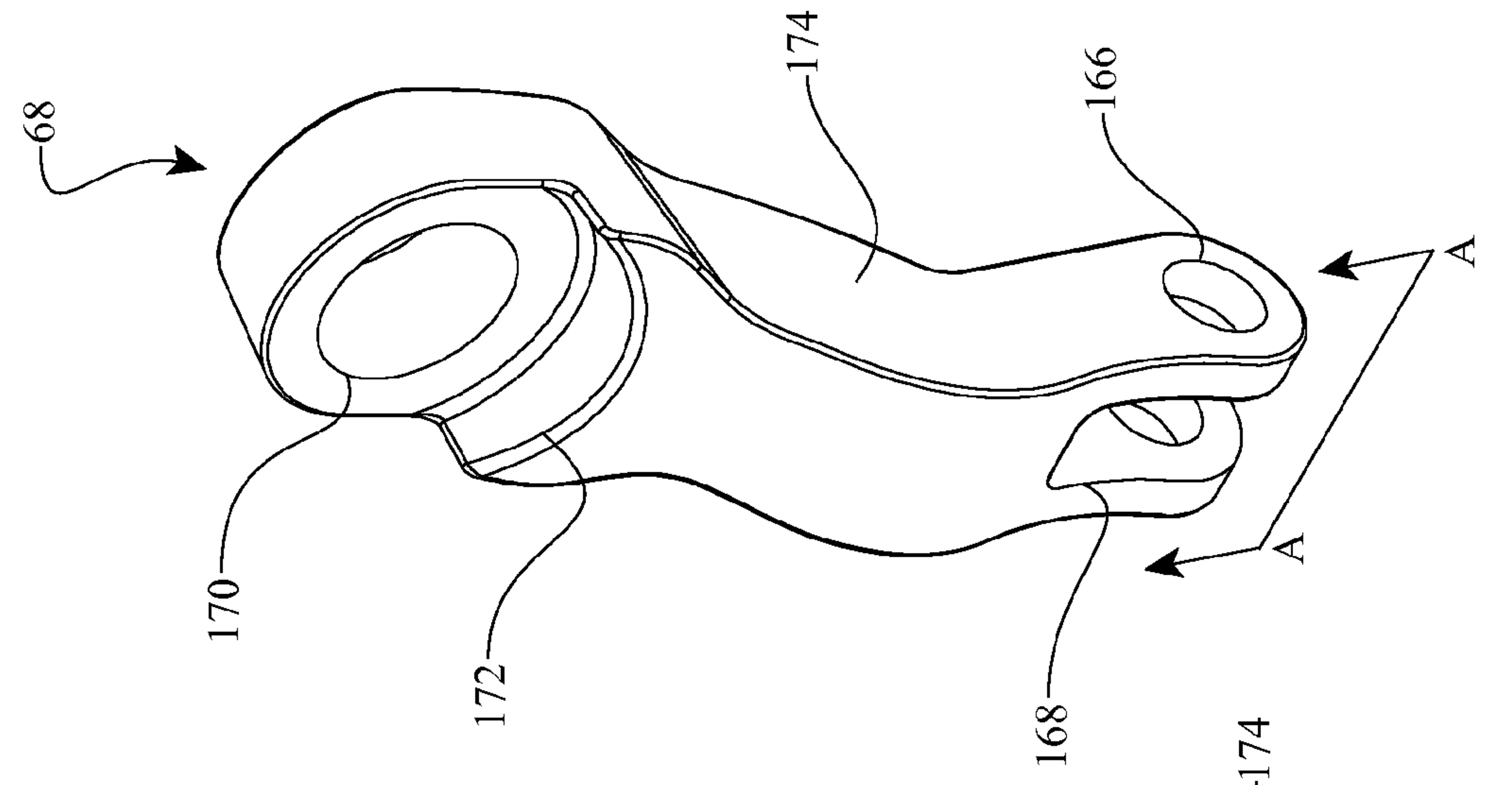


FIG. 12A

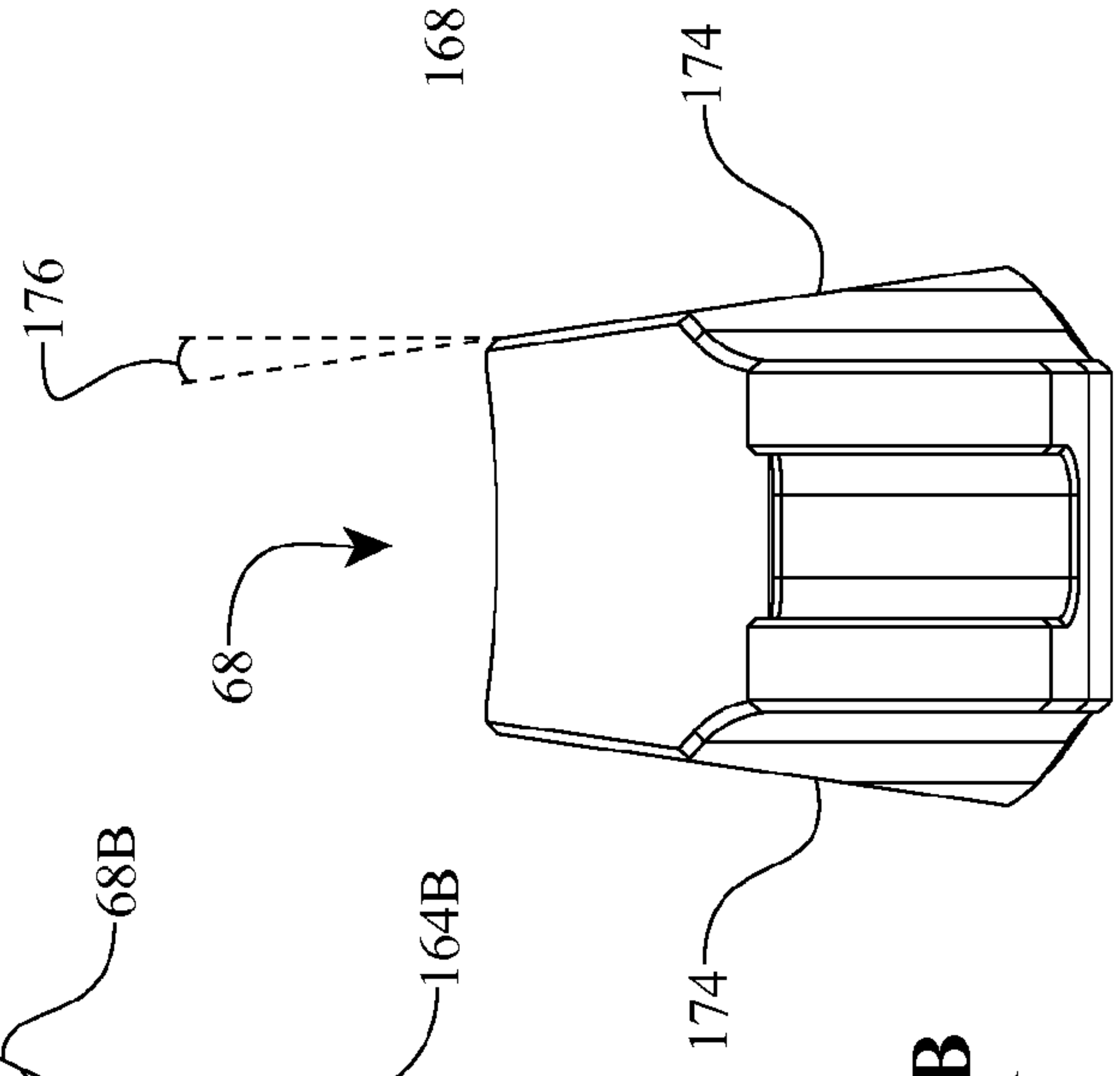


FIG. 12B
VIEW A-A

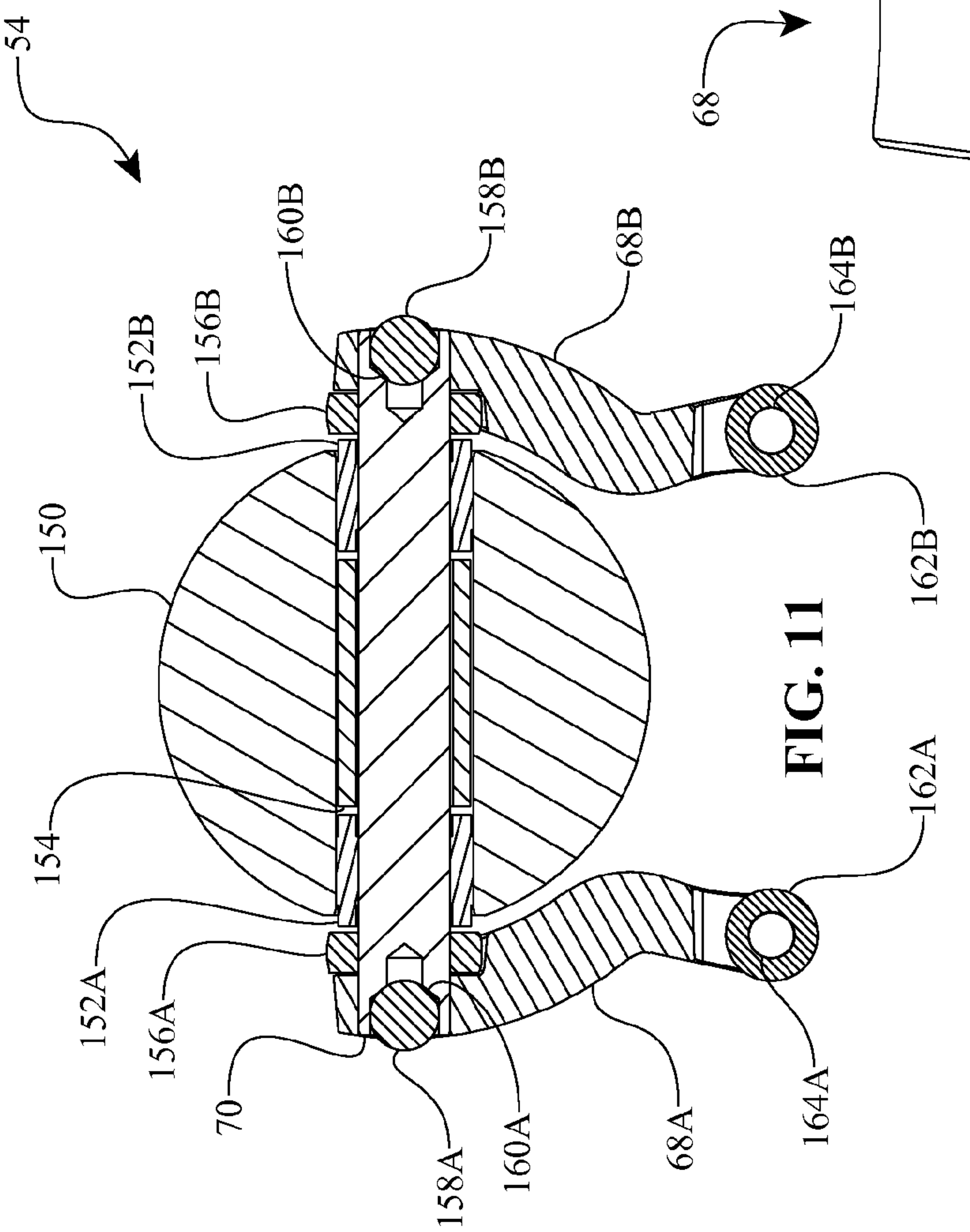


FIG. 11

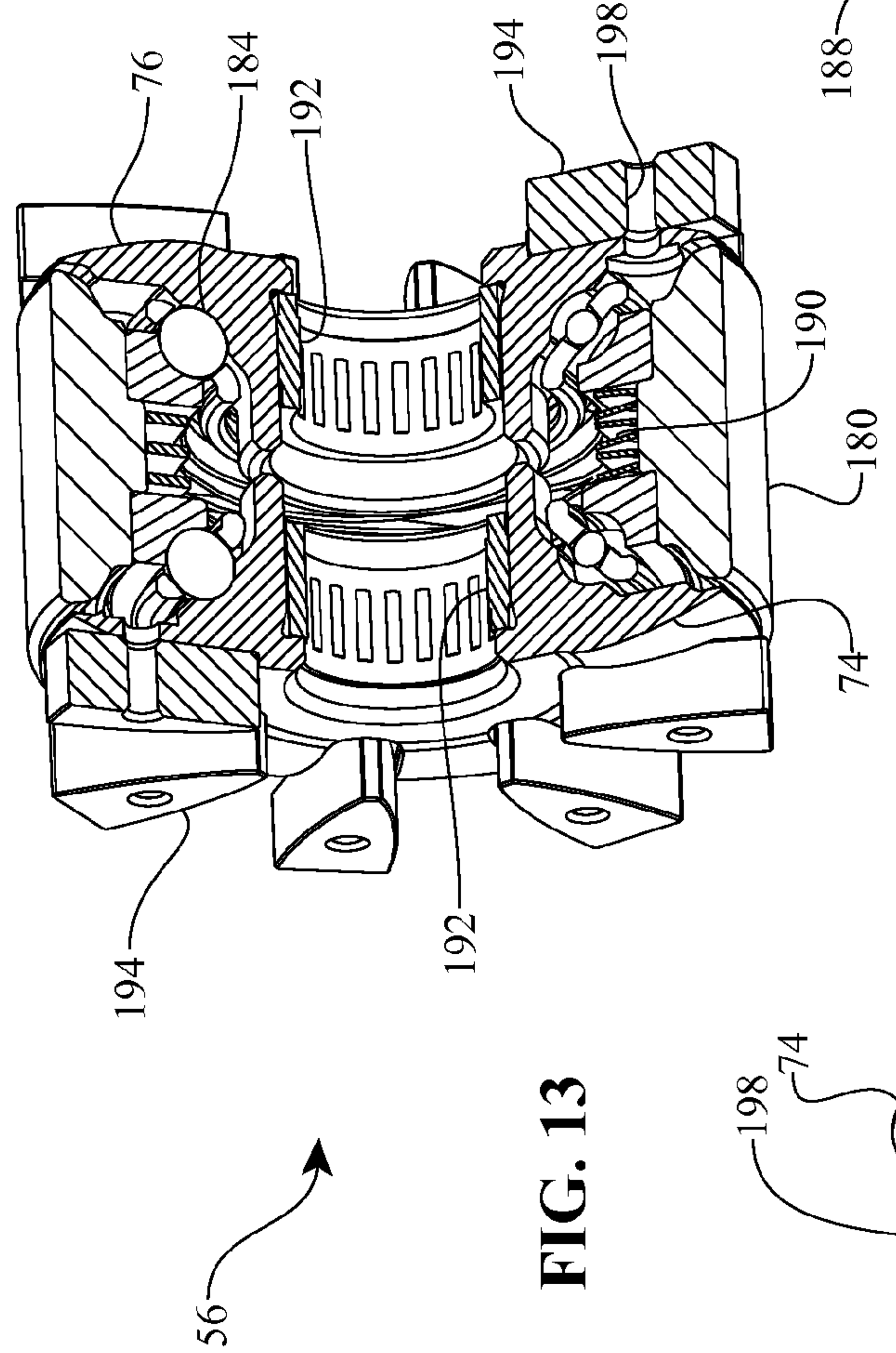

76
184
192
194
198
190
180
74
194
192
56

FIG. 13

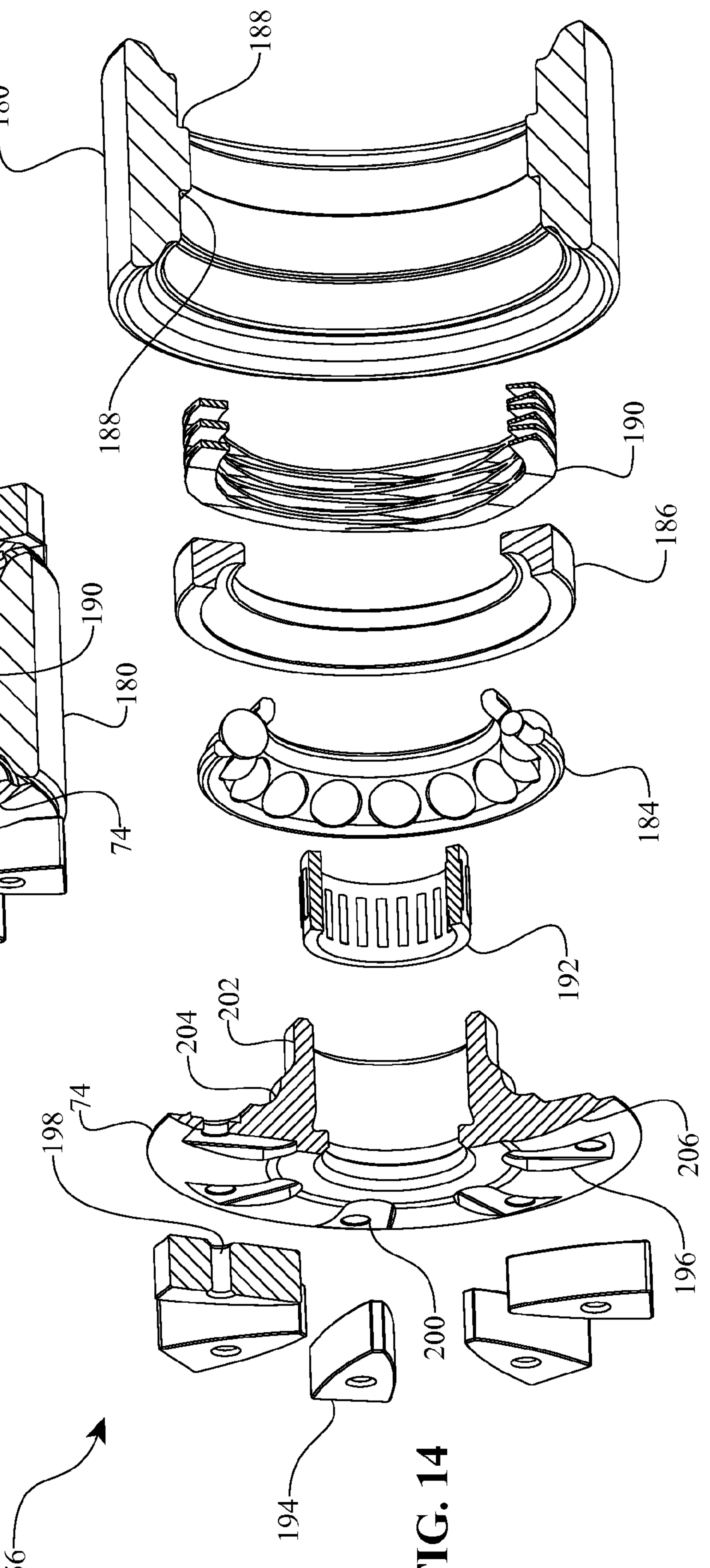

180
188
188
190
186
184
192
202
204
74
198
206
196
200
194
56

FIG. 14

WO 2010/044778 PCT/US2008/079879

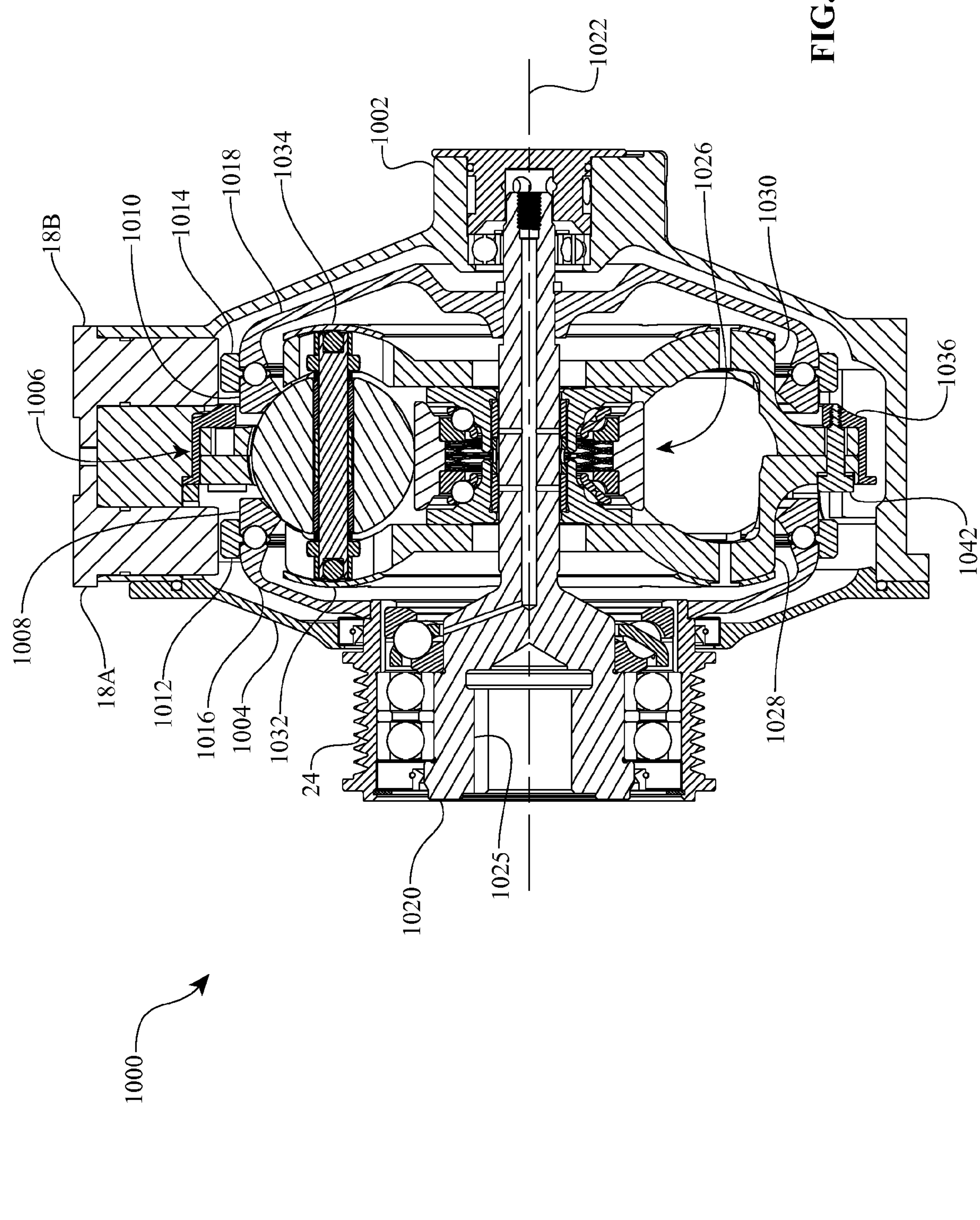


FIG. 15

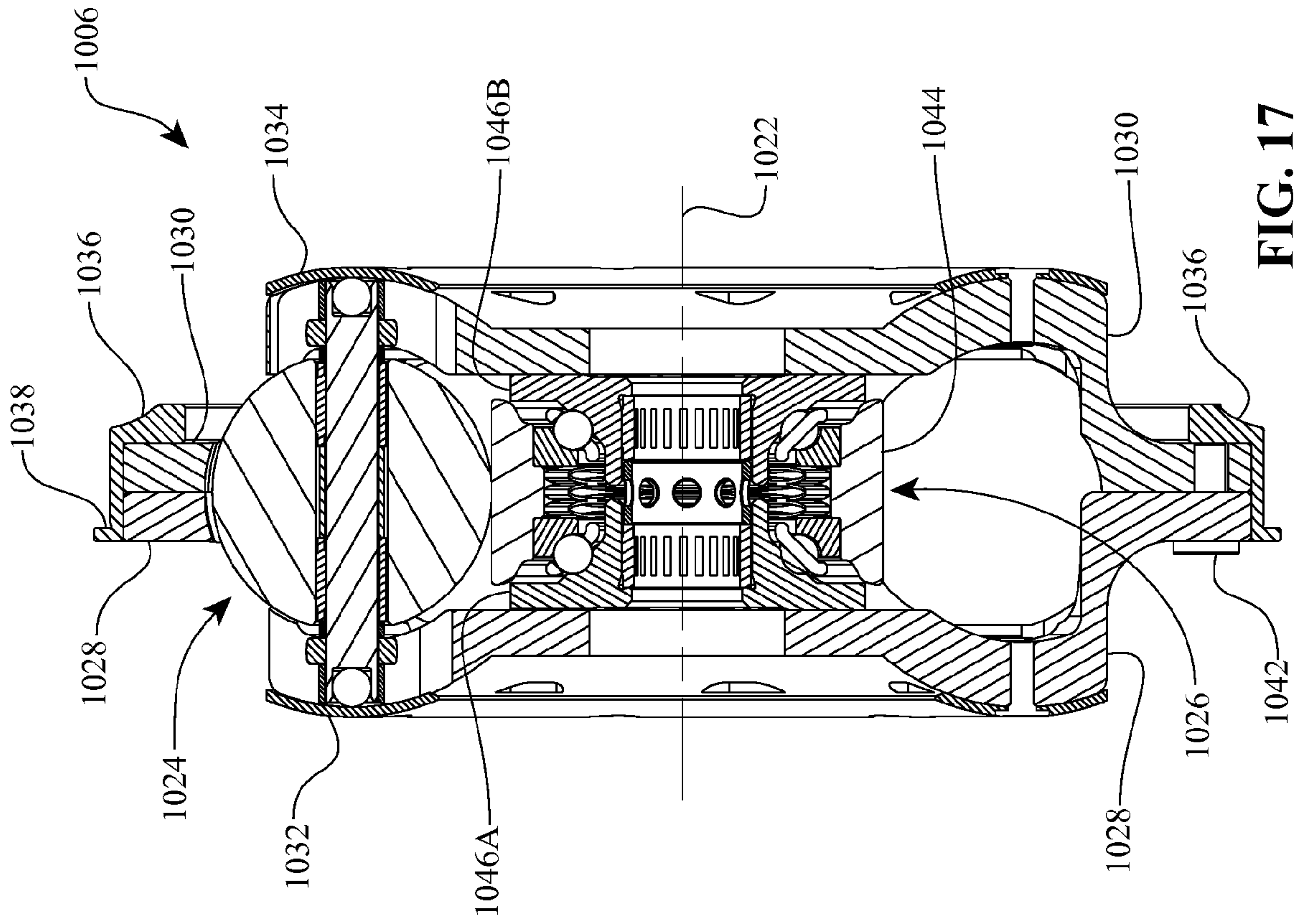

1006
1034
1046B
1022
1044
1030
1036
1030
1038
1028
1024
1032
1046A
1028
1026
1042
1036

FIG. 17

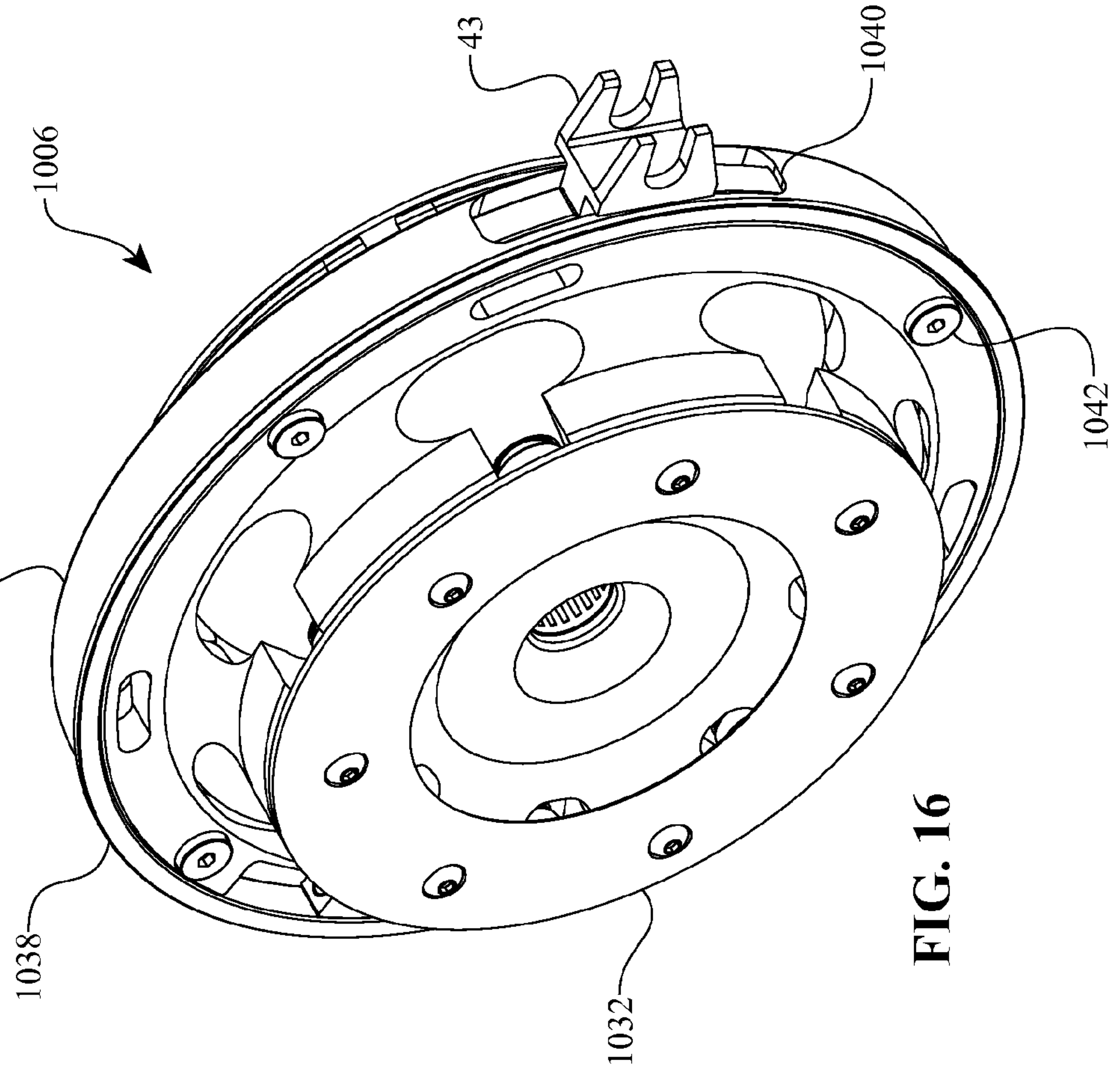

43
1040
1006
1042
1036
1038
1032

FIG. 16

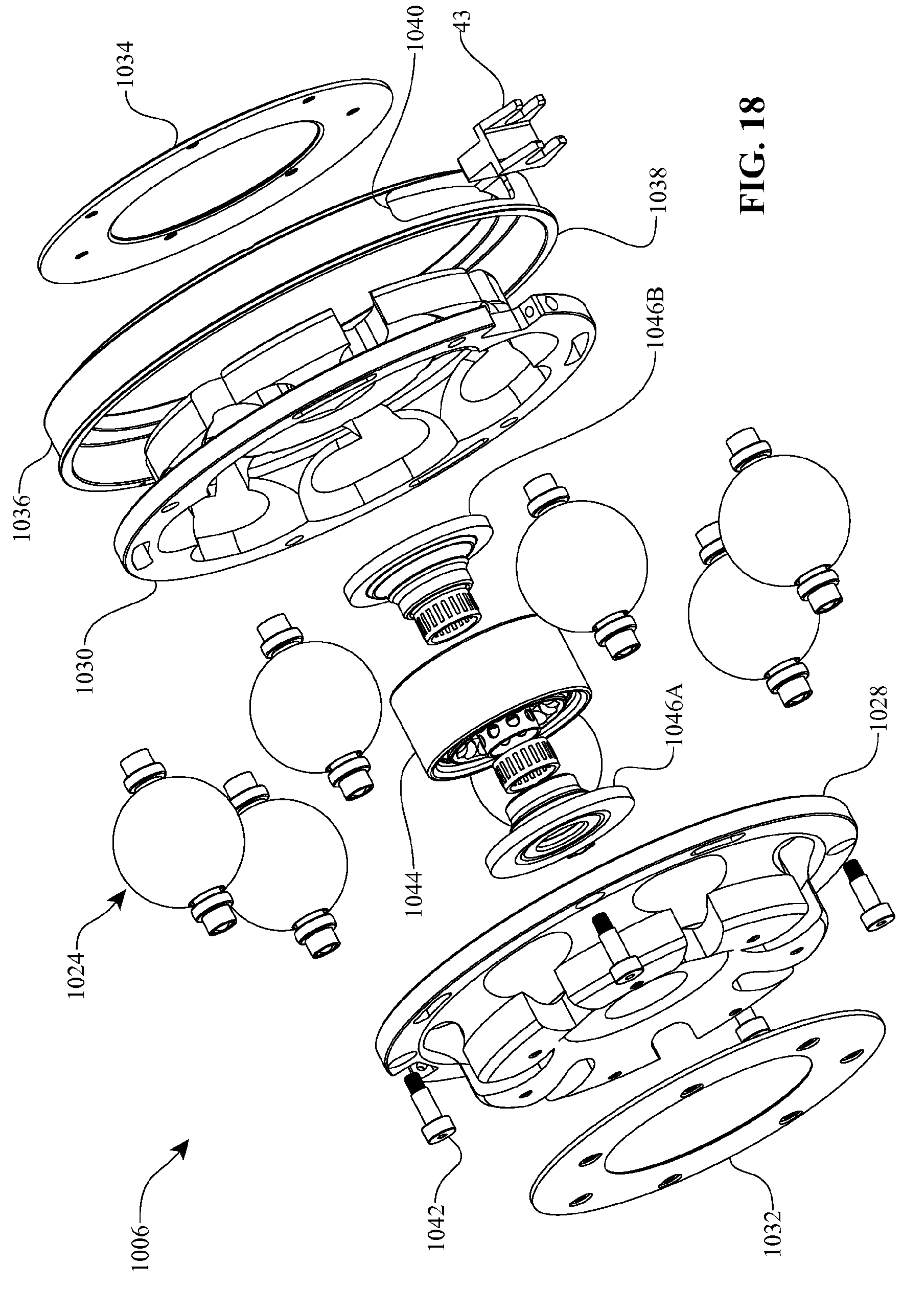

1034
1040
43
1038
1036
1046B
1030
1028
1046A
1044
1024
1042
1032
1006

FIG. 18

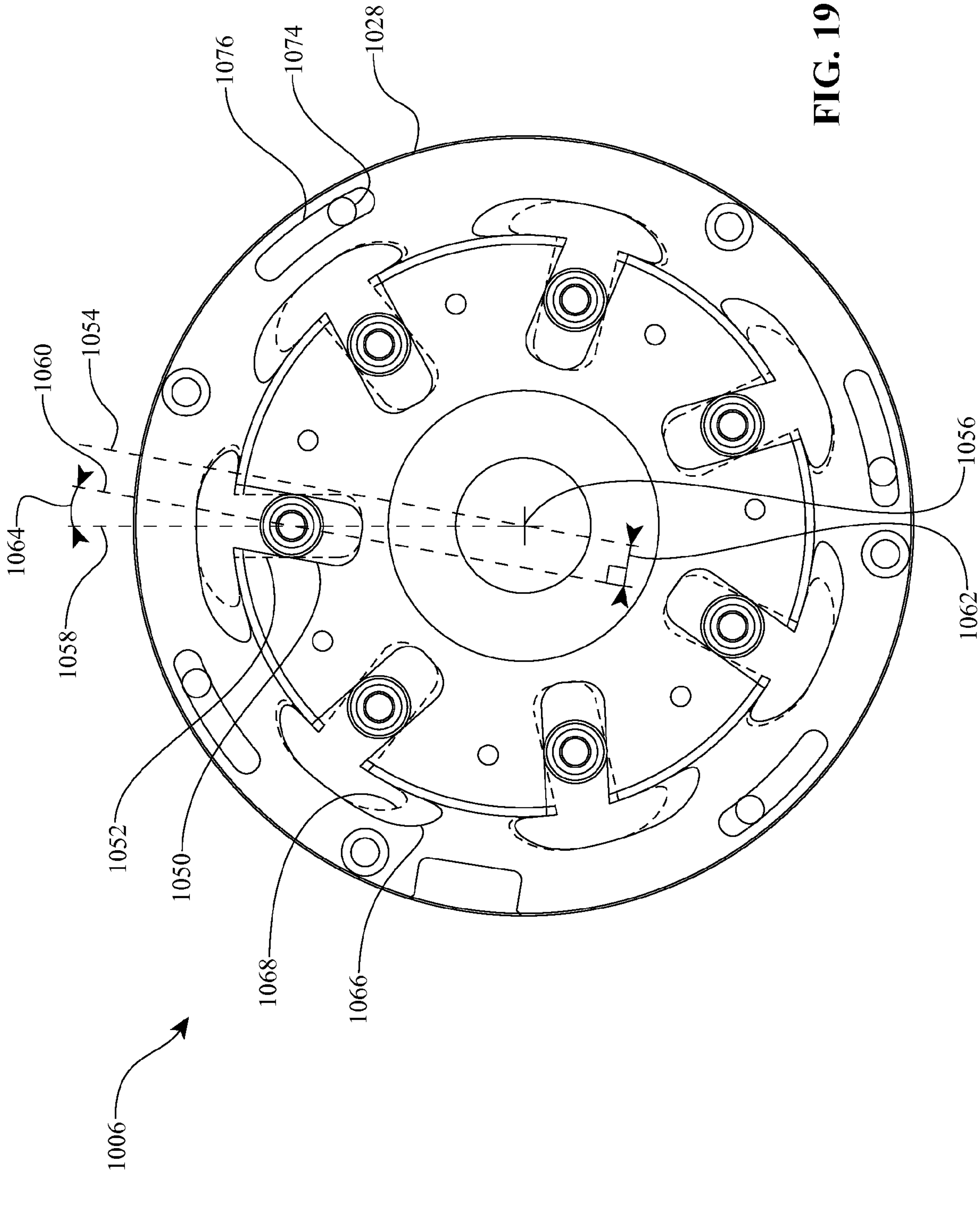

1076
1074
1028
1060
1054
1064
1058
1056
1062
1052
1050
1068
1066
1006

FIG. 19

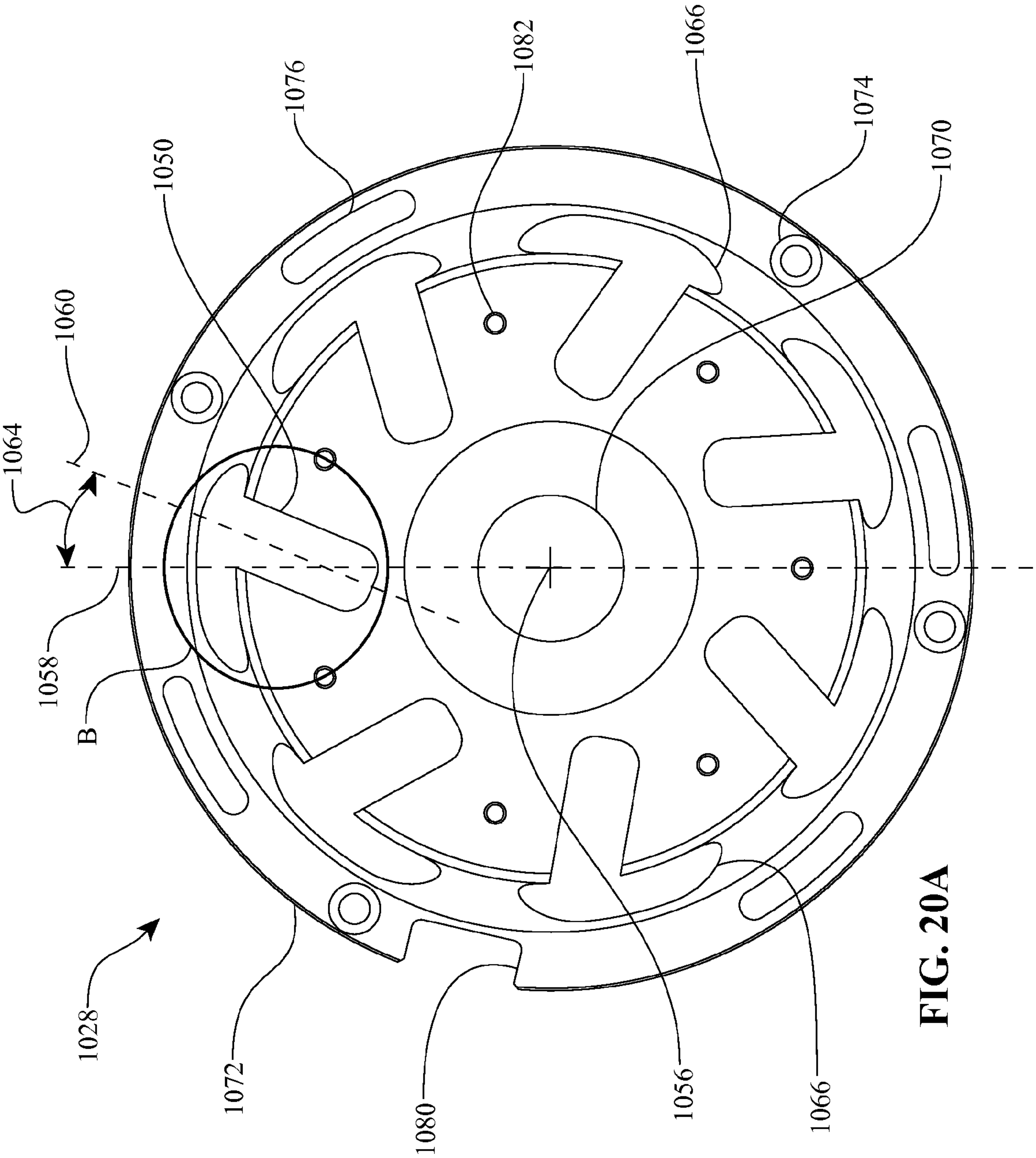

1082
1066
1076
1074
1050
1070
1060
1064
1058
B
1028
1072
1080
1056
1066

FIG. 20A

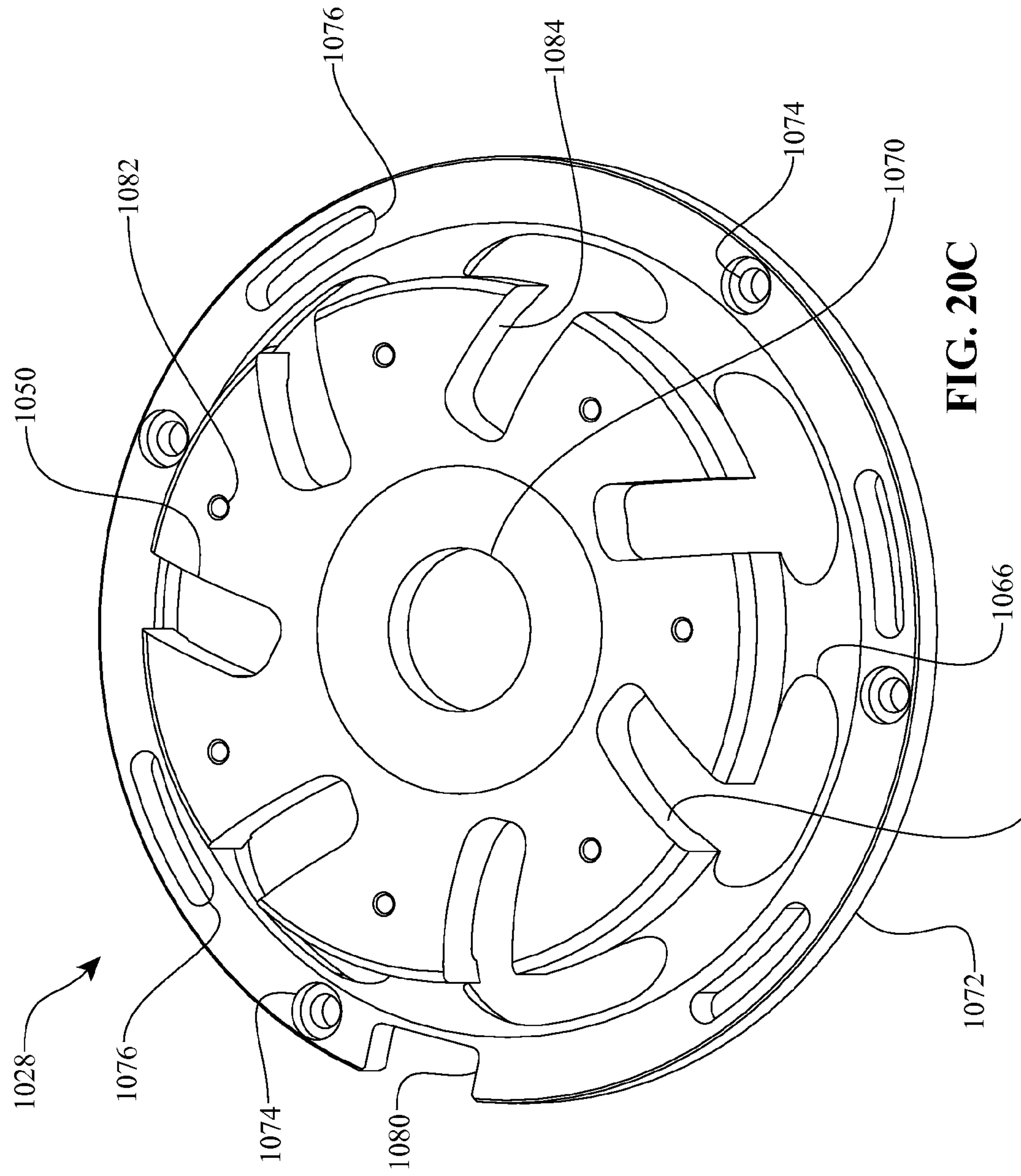


FIG. 20C

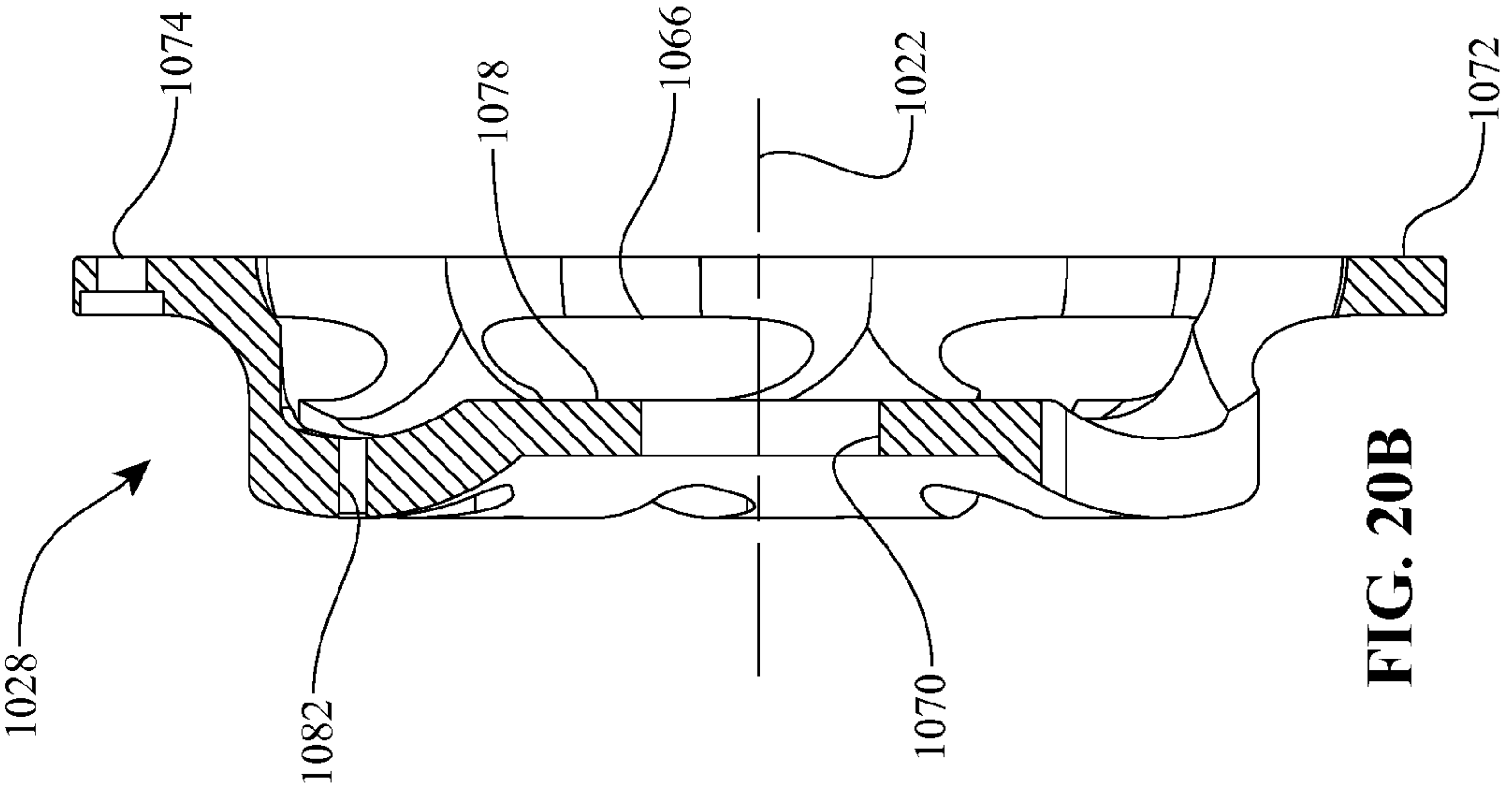


FIG. 20B

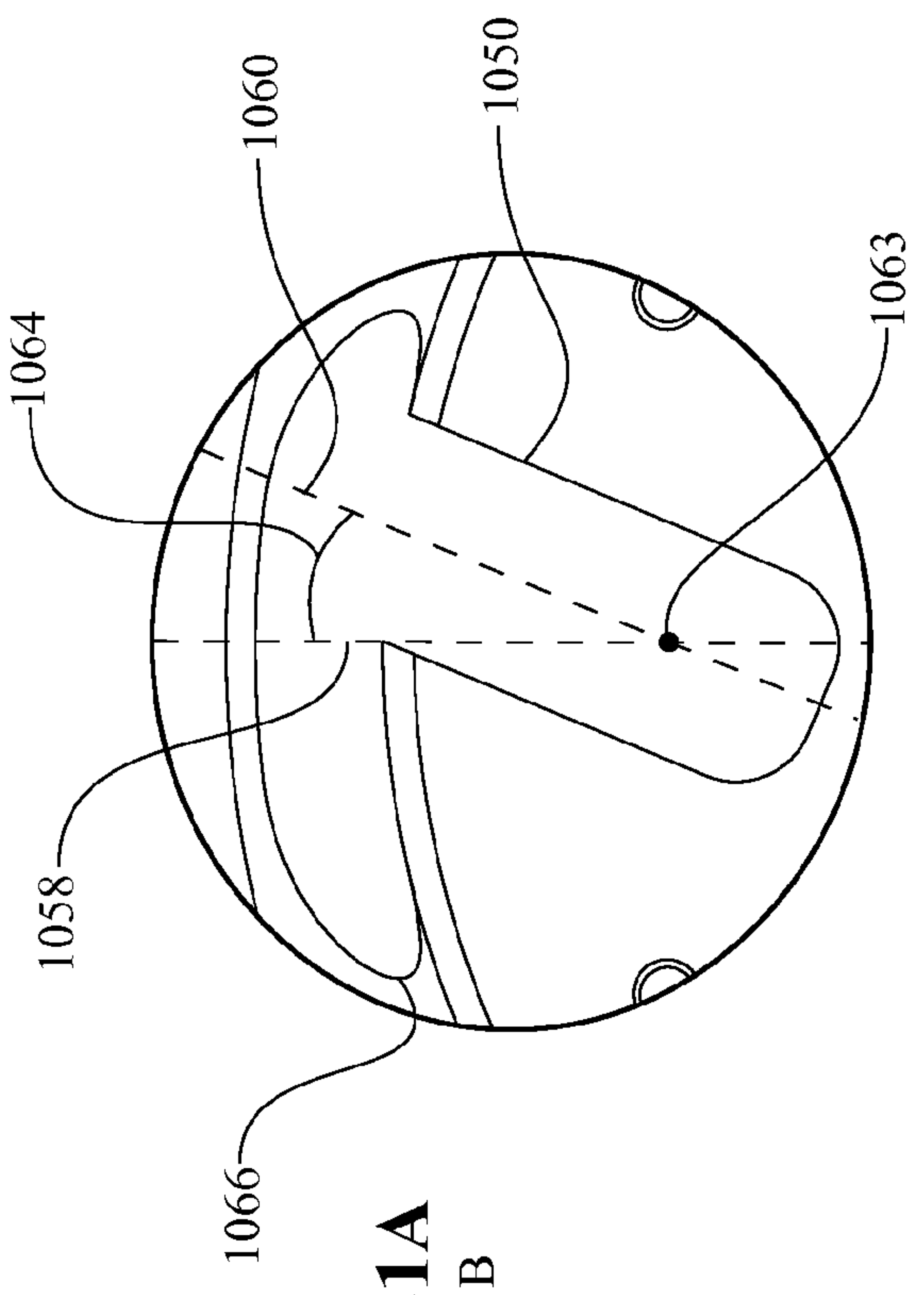


FIG. 21A
DETAIL B

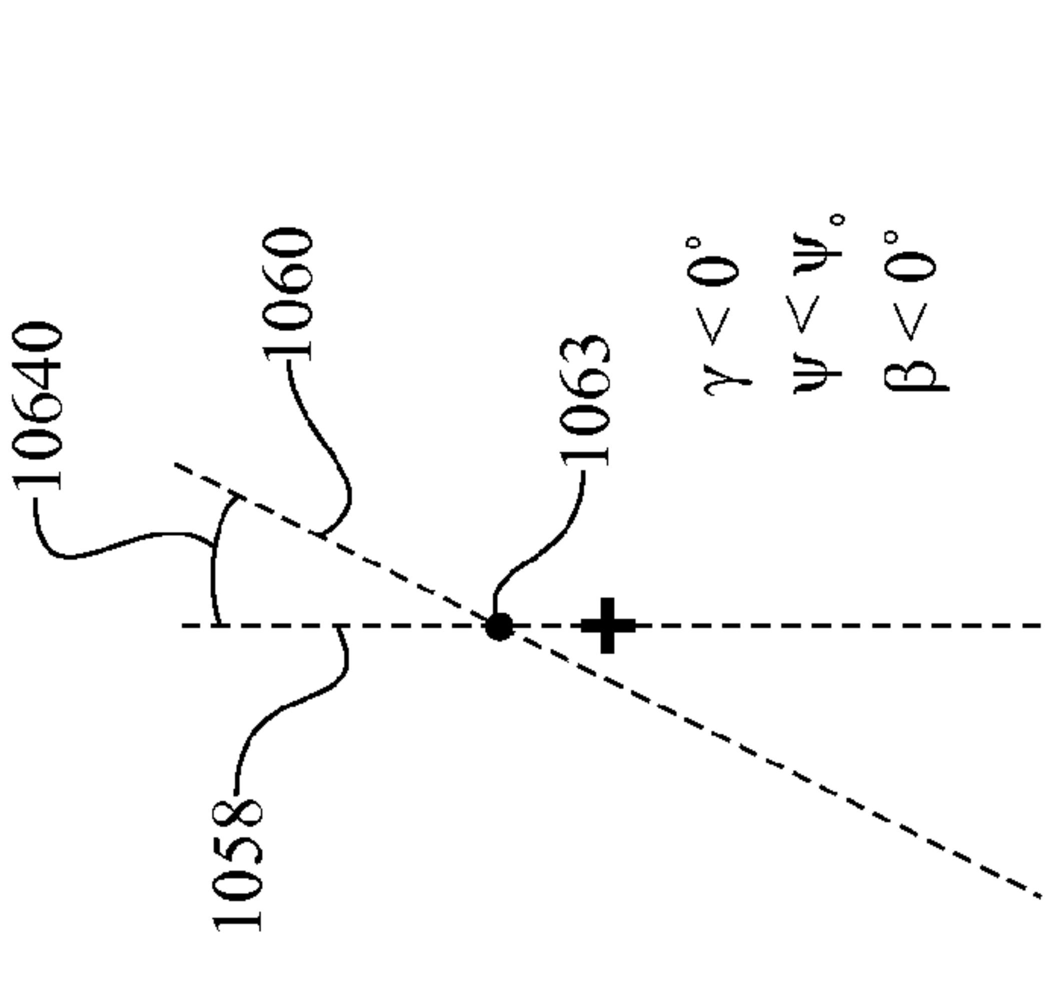


FIG. 21B

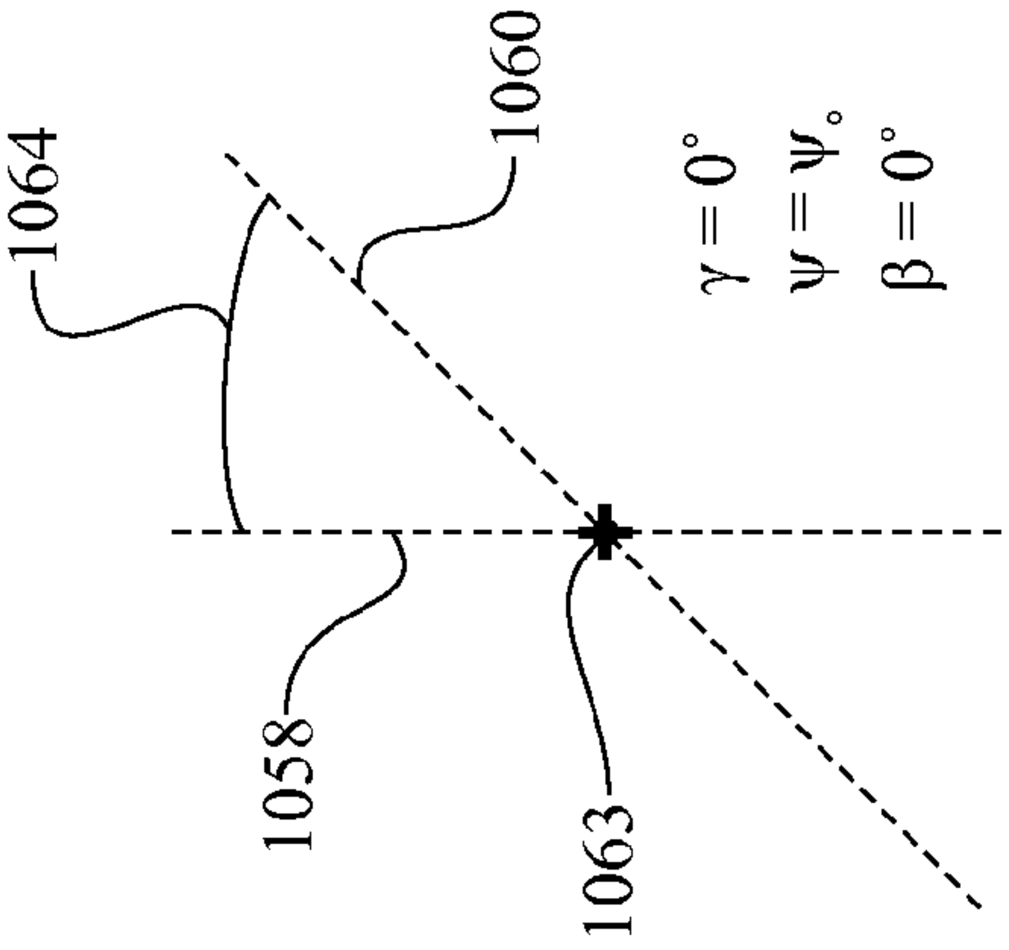


FIG. 21C

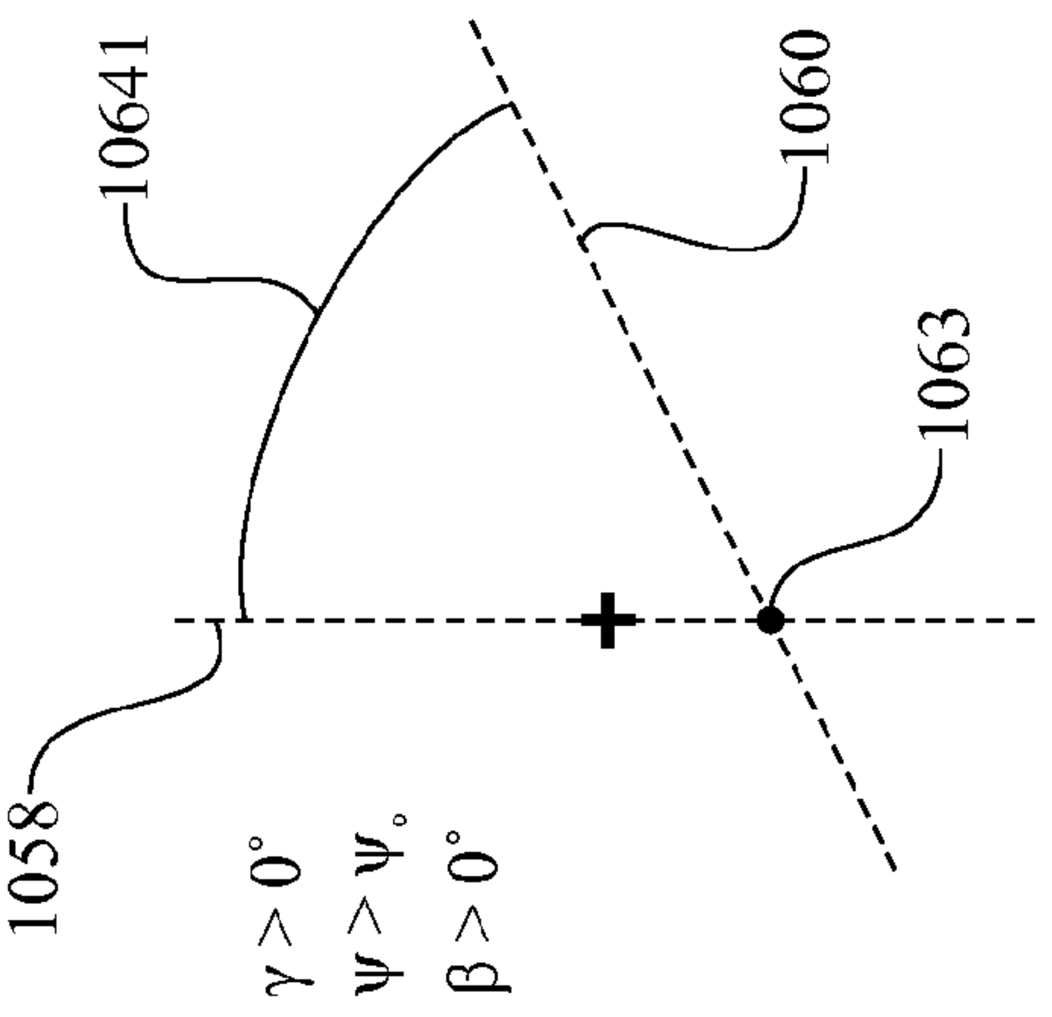


FIG. 21D

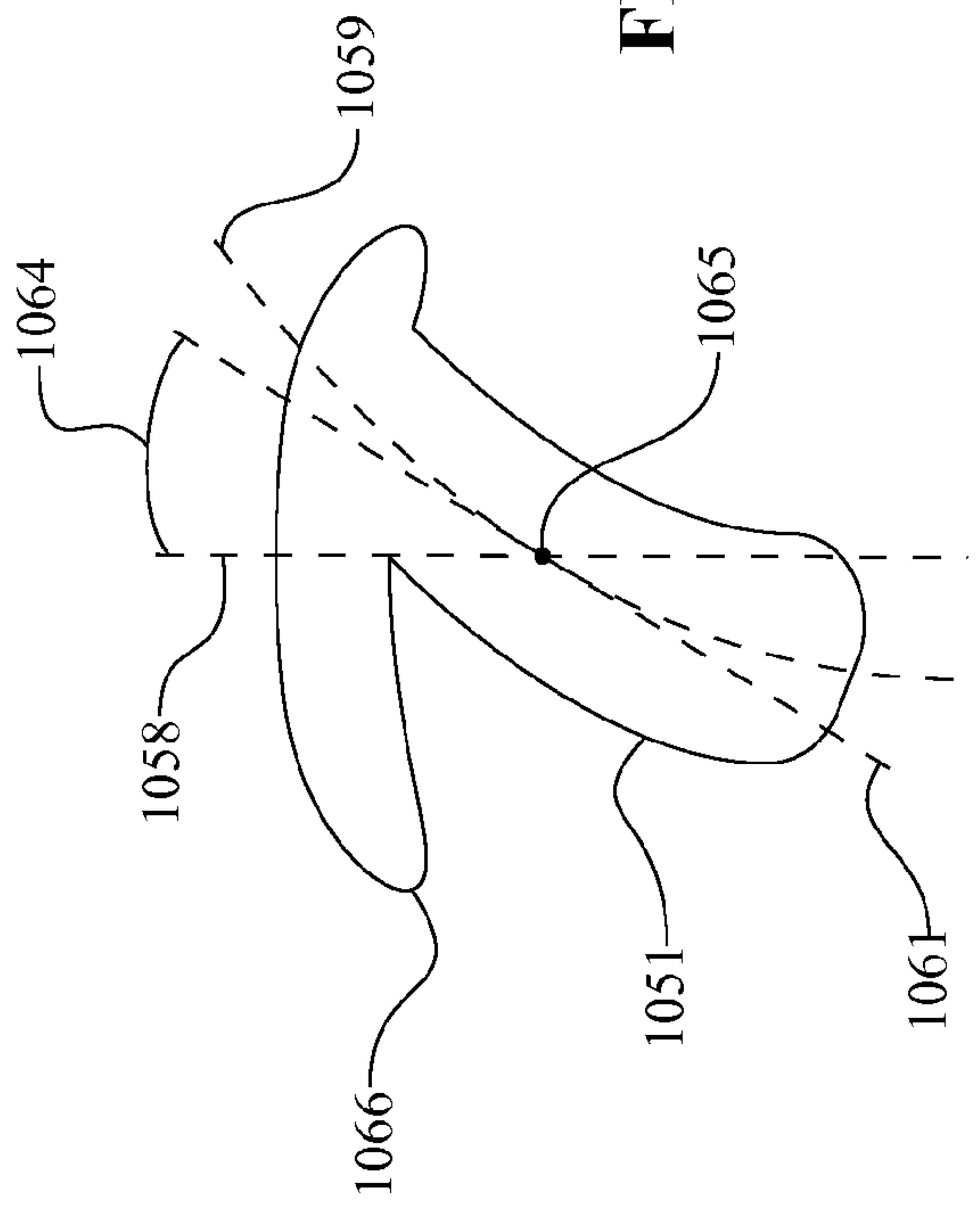


FIG. 21E

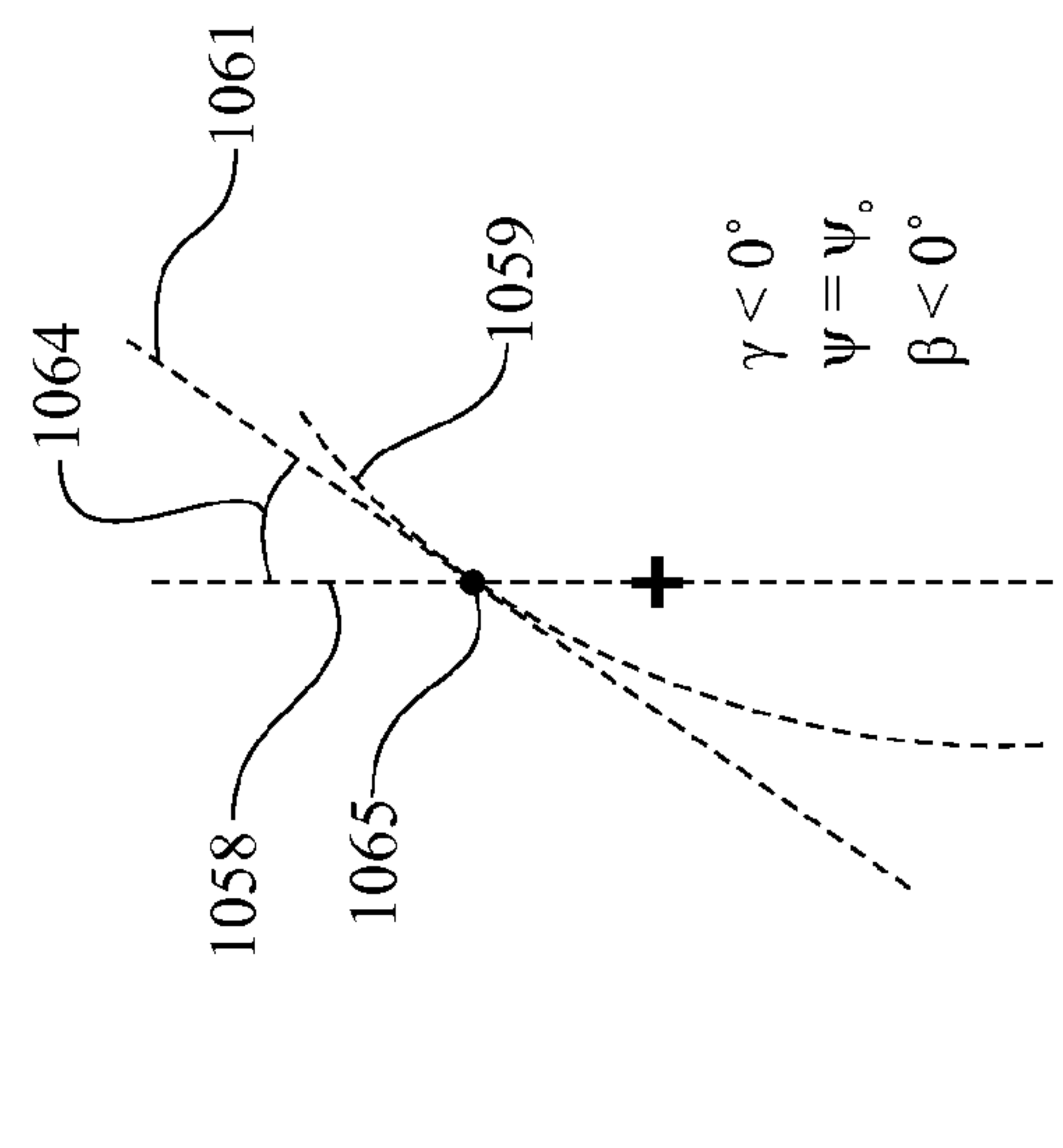


FIG. 21F

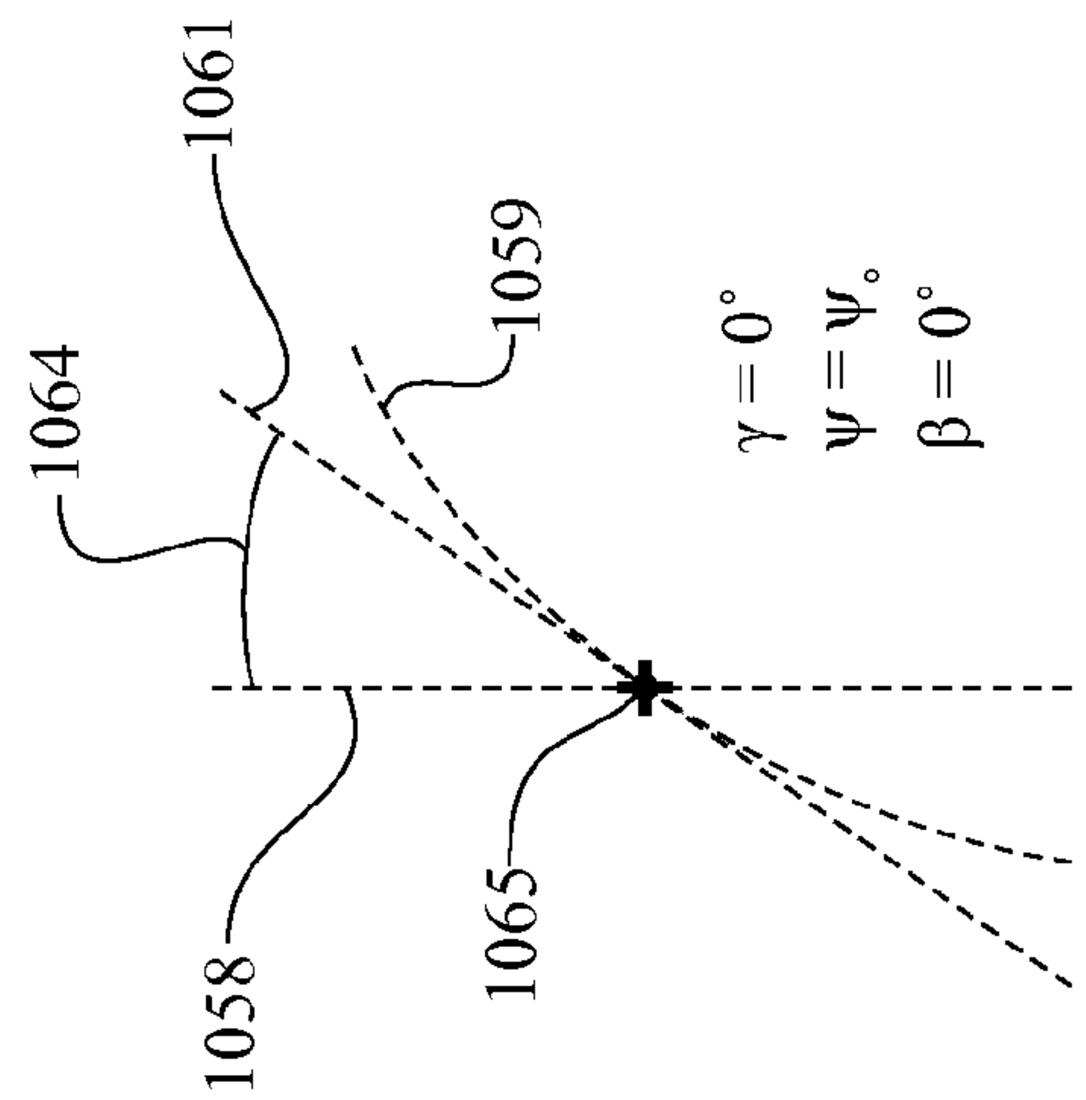


FIG. 21G

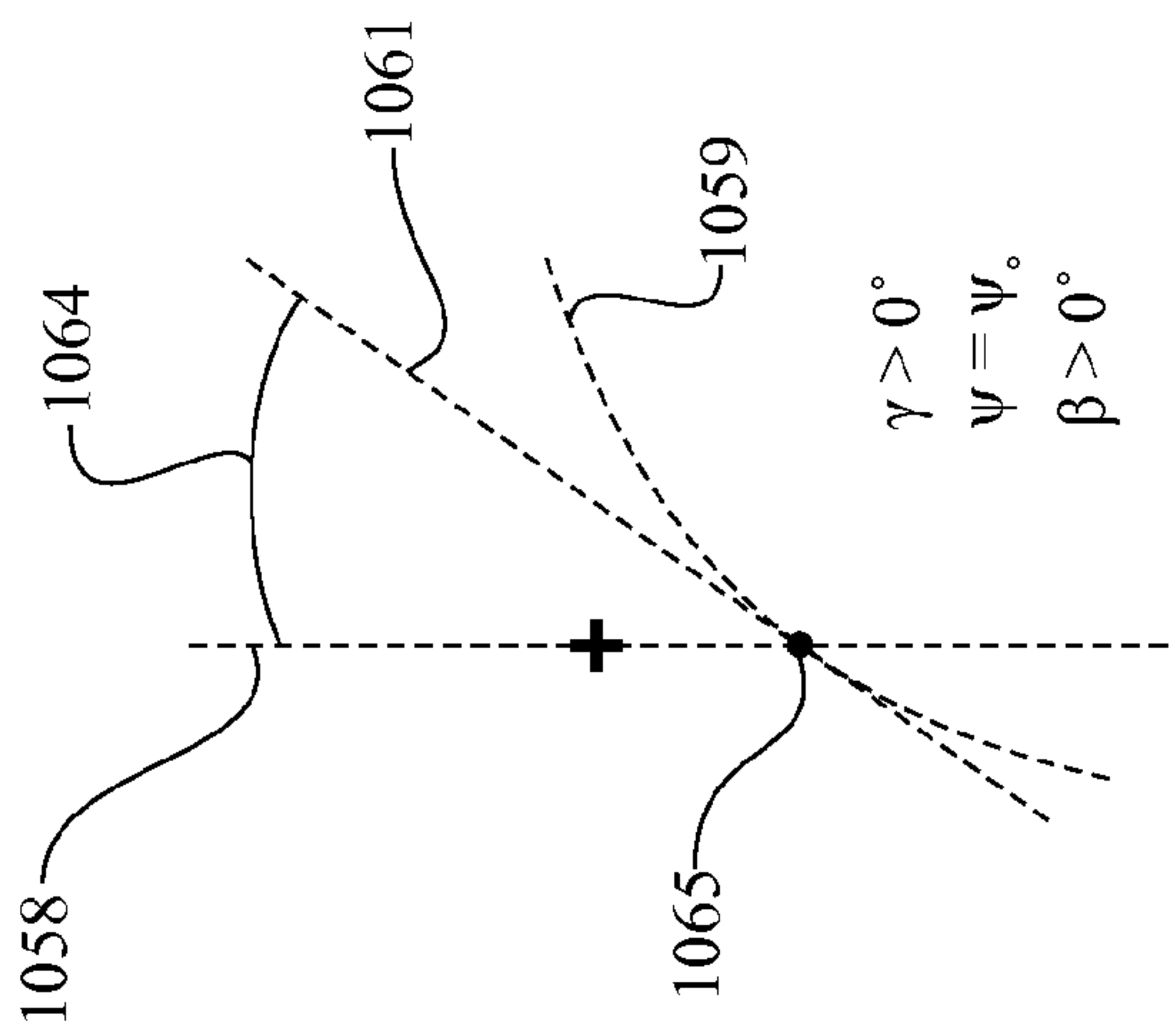


FIG. 21H

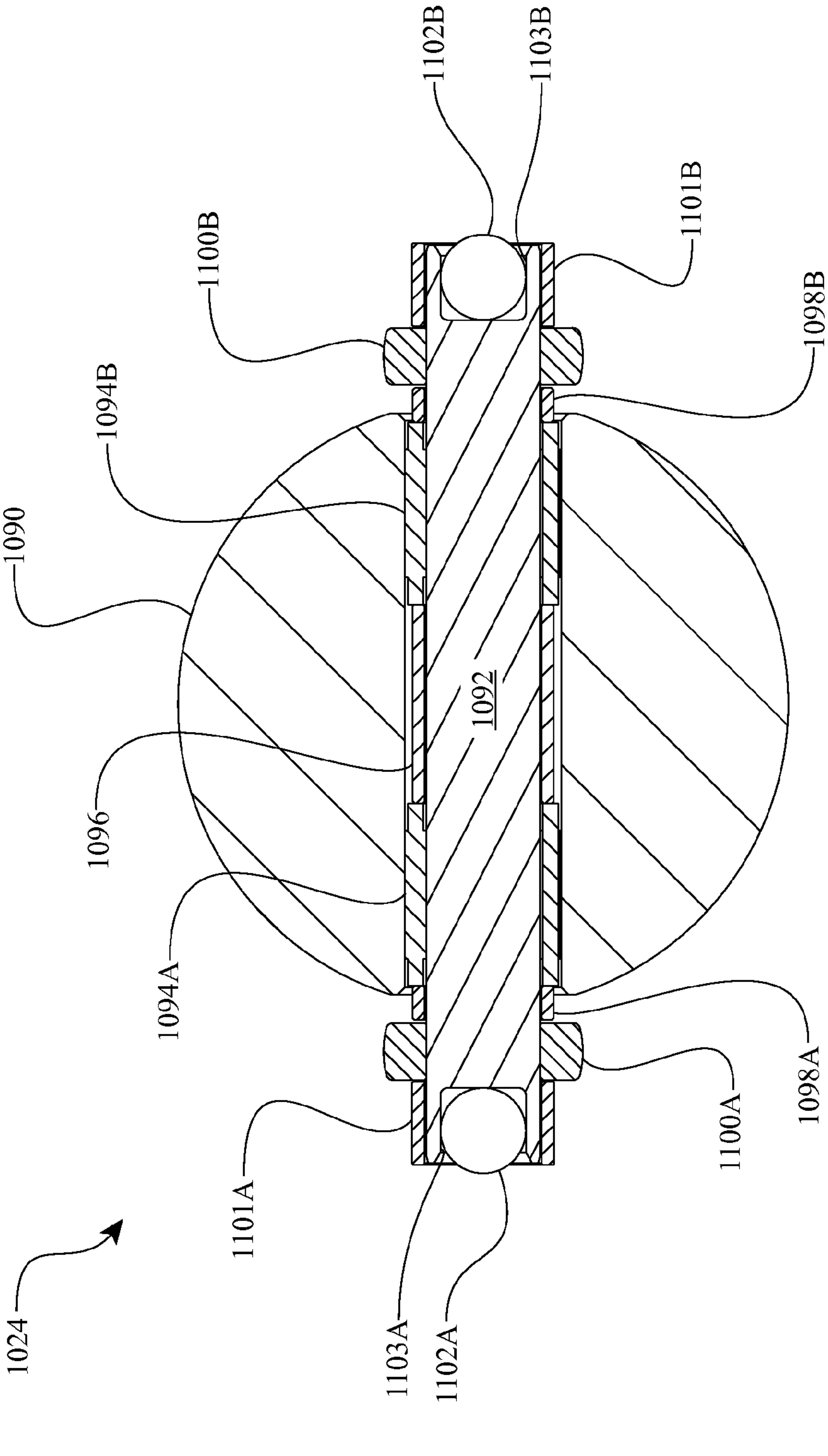

1024
1090
1092
1094A
1094B
1096
1098A
1098B
1100A
1100B
1101A
1101B
1102A
1102B
1103A
1103B

FIG. 22

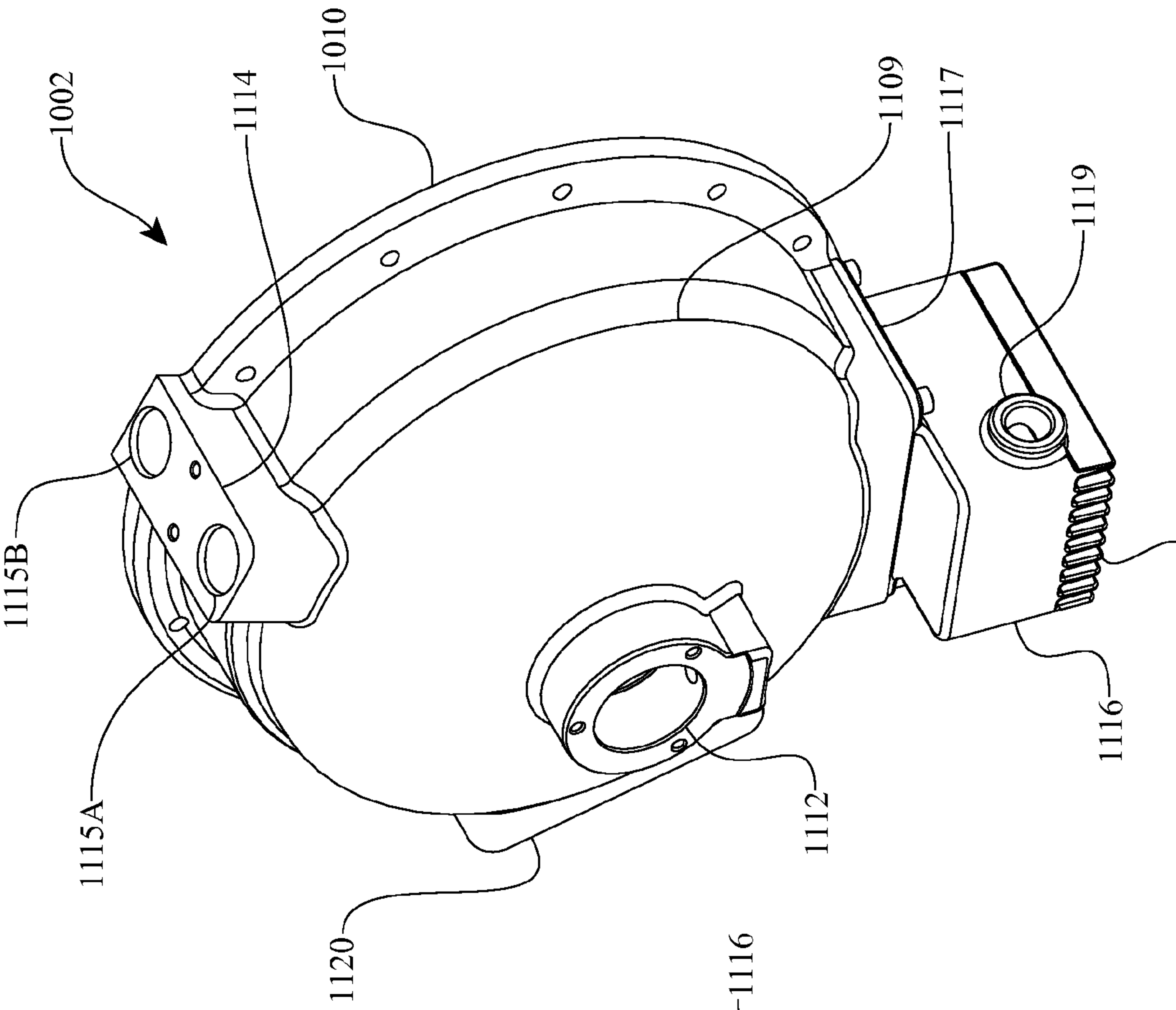

1002
1010
1114
1109
1117
1119
1115B
1115A
1112
1120
1116
1118

FIG. 24

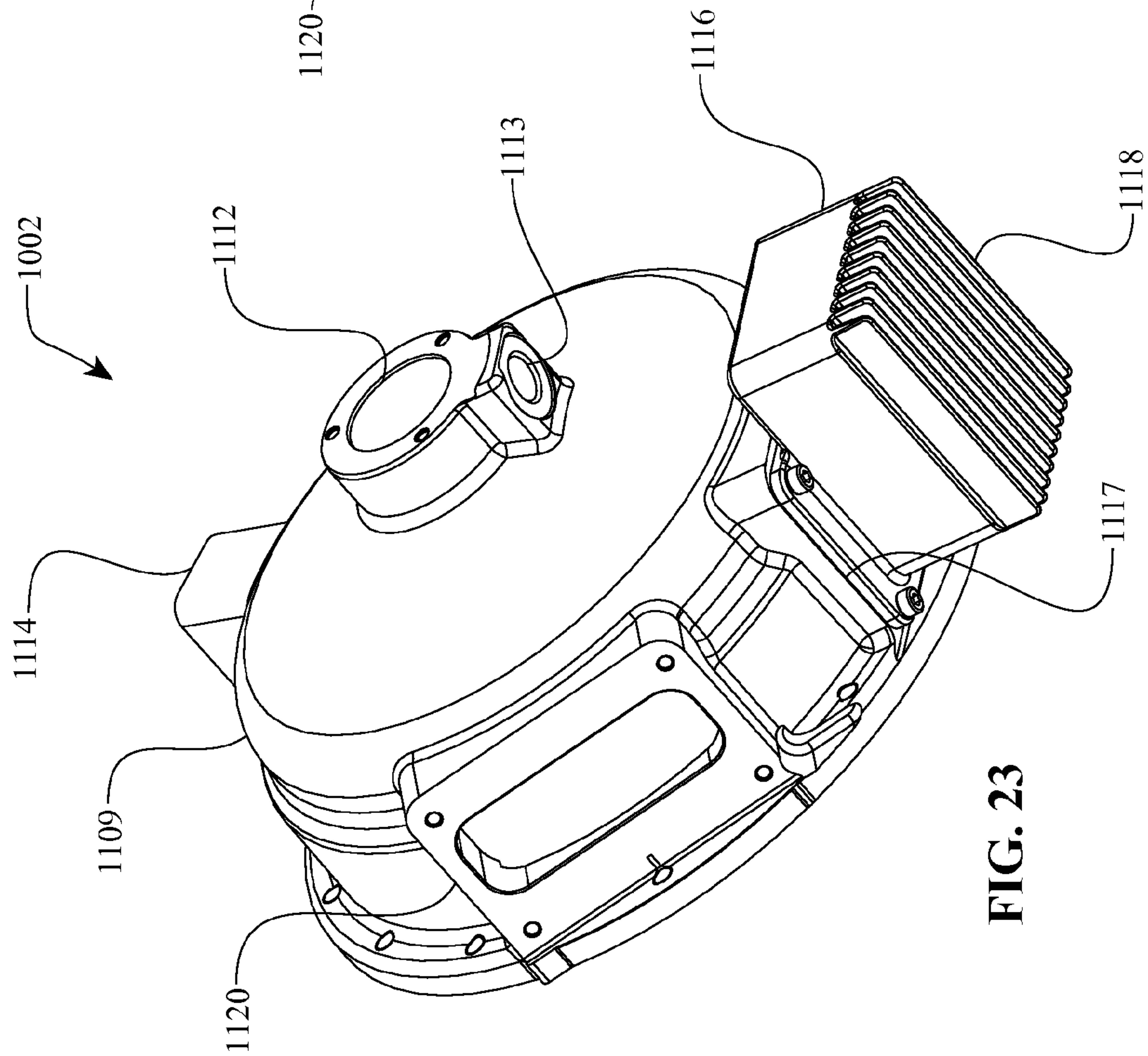

1002
1112
1113
1116
1118
1114
1117
1109
1120

FIG. 23

FIG. 25

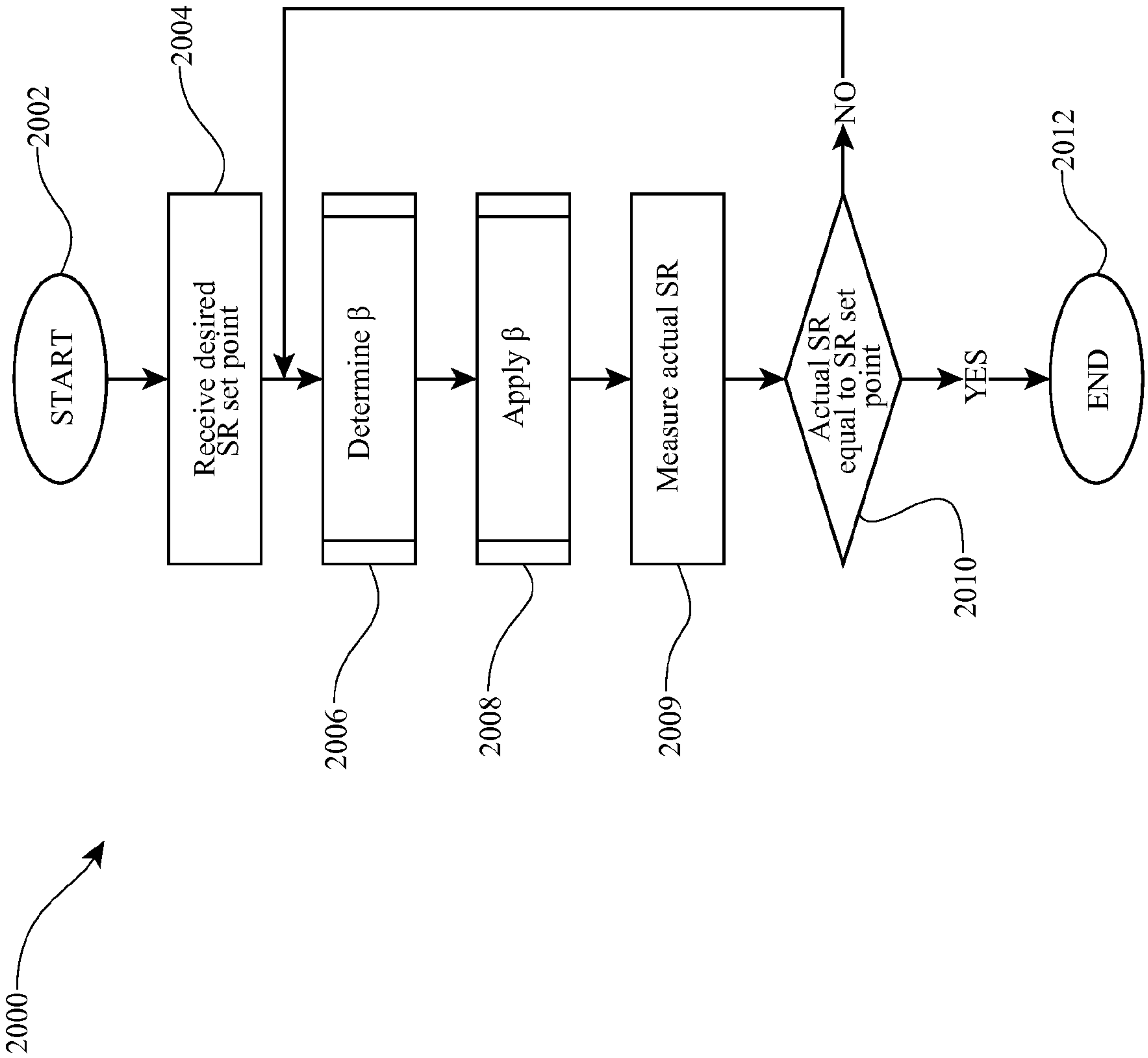
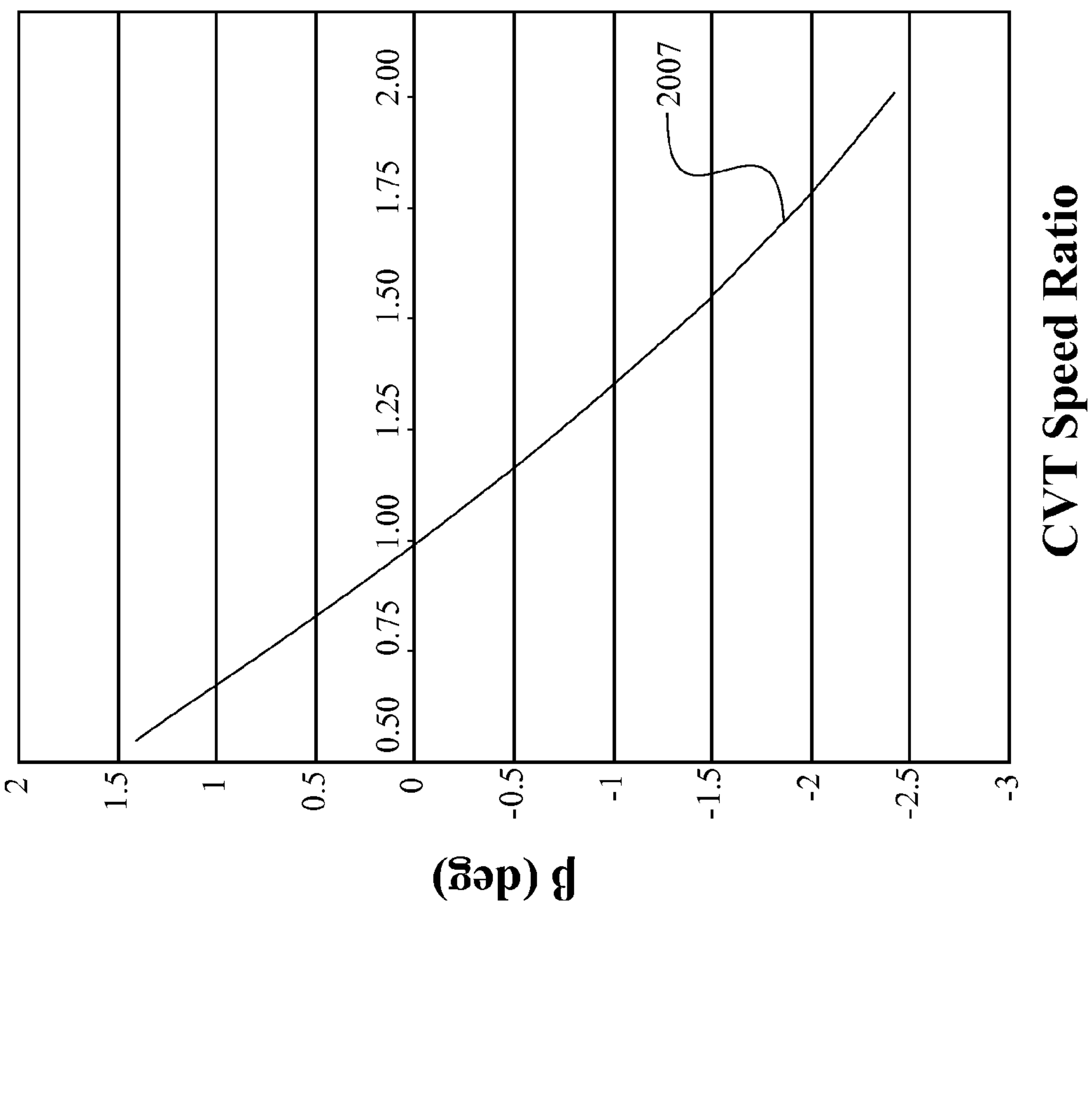

2000
START
2002
Receive desired SR set point
2004
Determine β
2006
Apply β
2008
Measure actual SR
2009
Actual SR equal to SR set point
2010
NO
YES
END
2012

FIG. 26


2007
0.50
0.75
1.00
1.25
1.50
1.75
2.00
CVT Speed Ratio
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
β (deg)

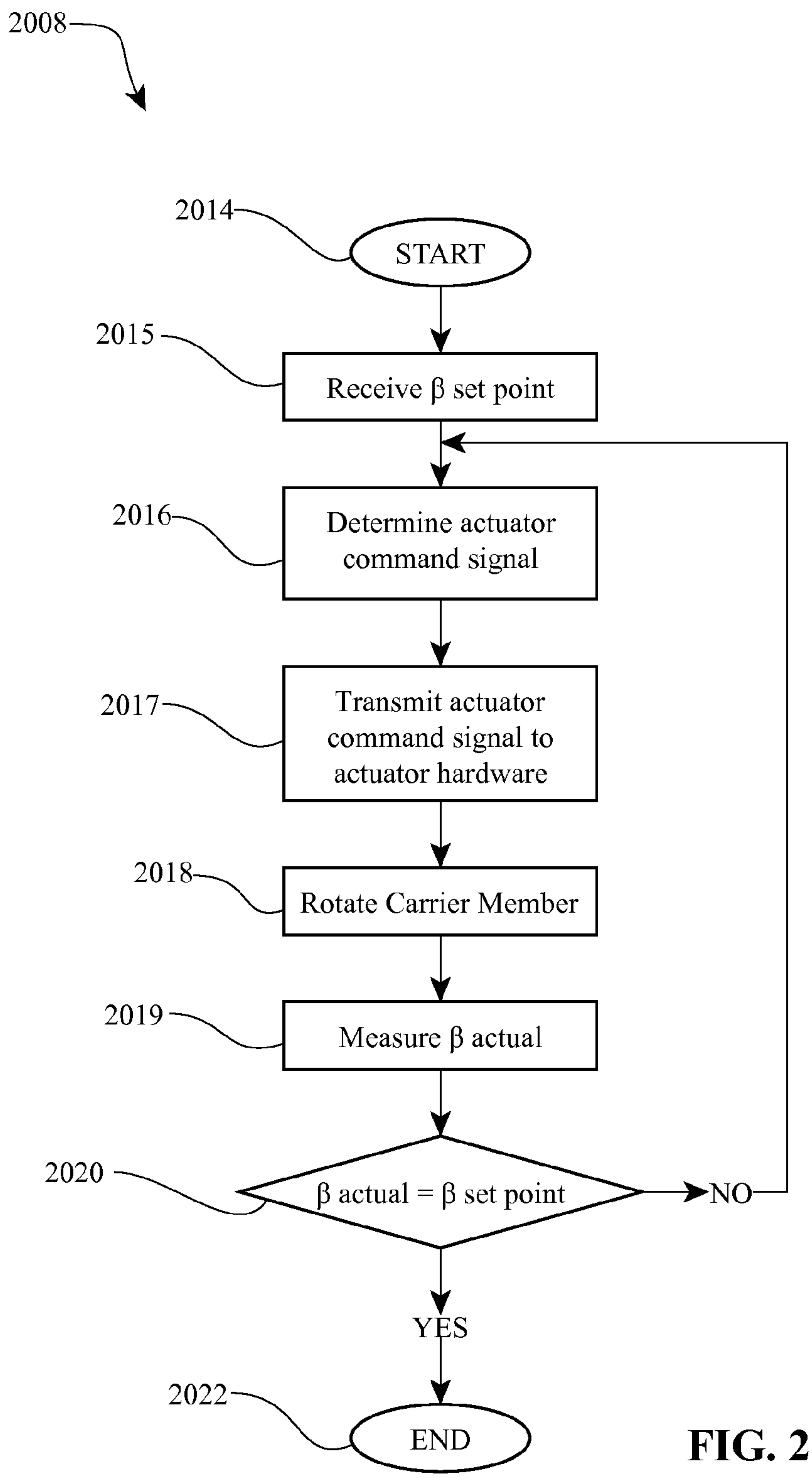

2008
2014
START
2015
Receive β set point
2016
Determine actuator command signal
2017
Transmit actuator command signal to actuator hardware
2018
Rotate Carrier Member
2019
Measure β actual
2020
β actual = β set point
NO
YES
2022
END

FIG. 27

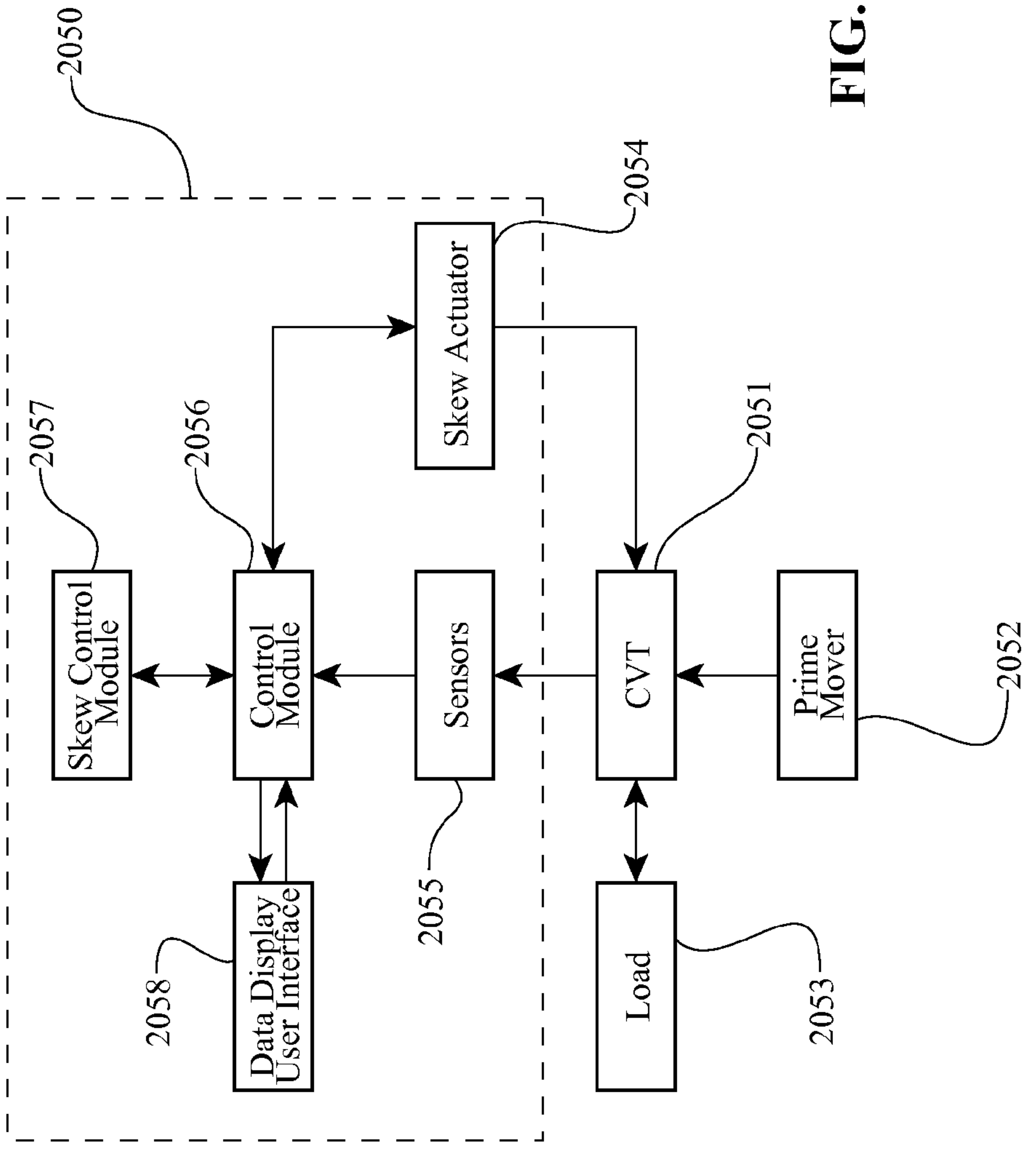

2050
2054
Skew Actuator
2057
2056
2051
Skew Control Module
Control Module
Sensors
CVT
Prime Mover
2052
2055
Data Display User Interface
Load
2058
2053

FIG. 28A

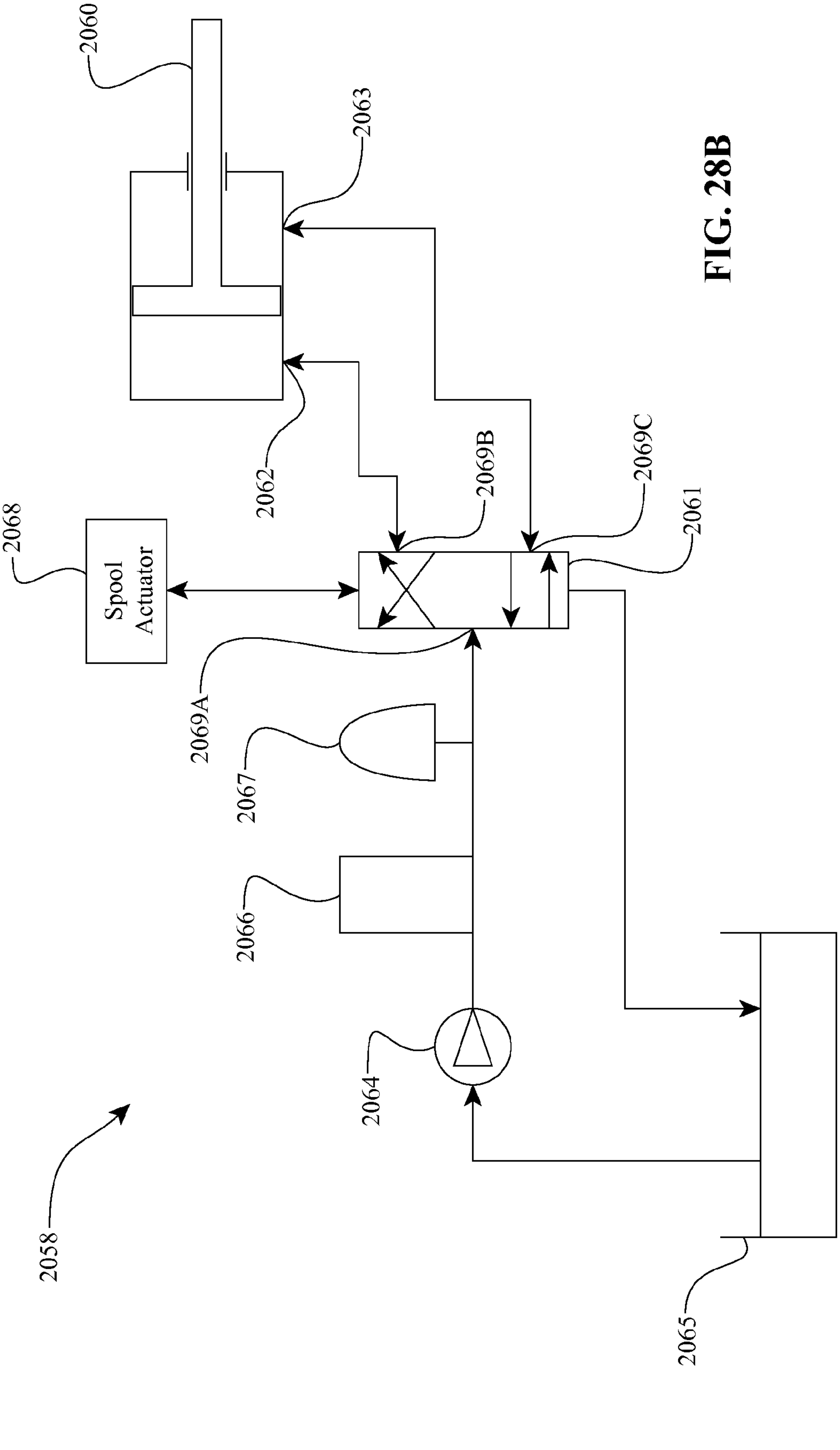

2060
2063
2062
2069B
2069C
2061
2068
Spool Actuator
2069A
2067
2066
2064
2058
2065

FIG. 28B

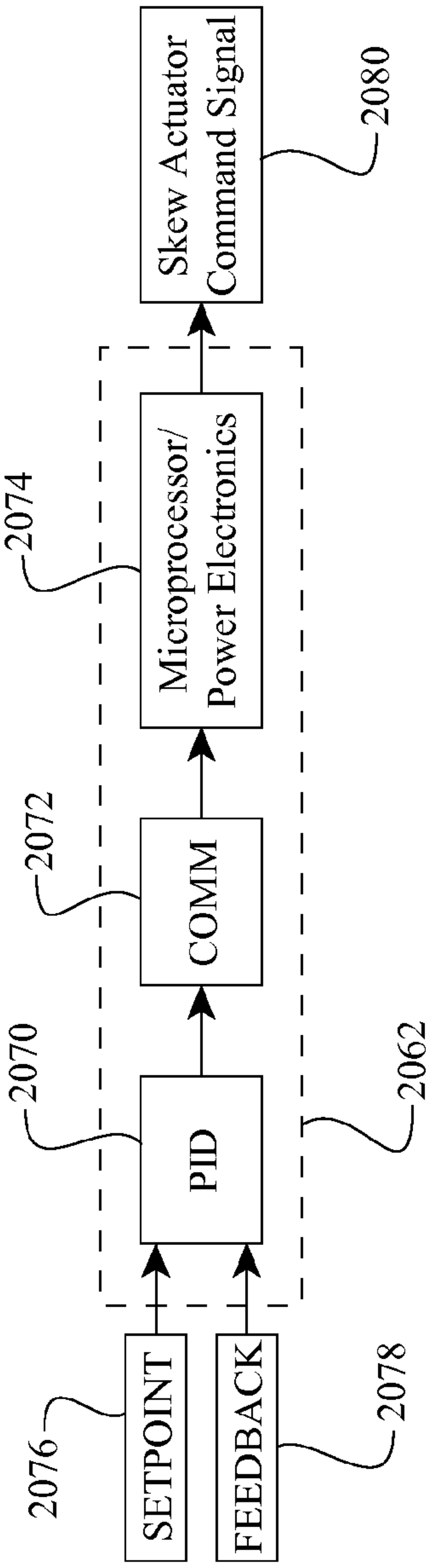

SETPOINT
FEEDBACK
2076
2078
PID
2070
COMM
2072
Microprocessor/
Power Electronics
2074
2062
Skew Actuator
Command Signal
2080

FIG. 29A

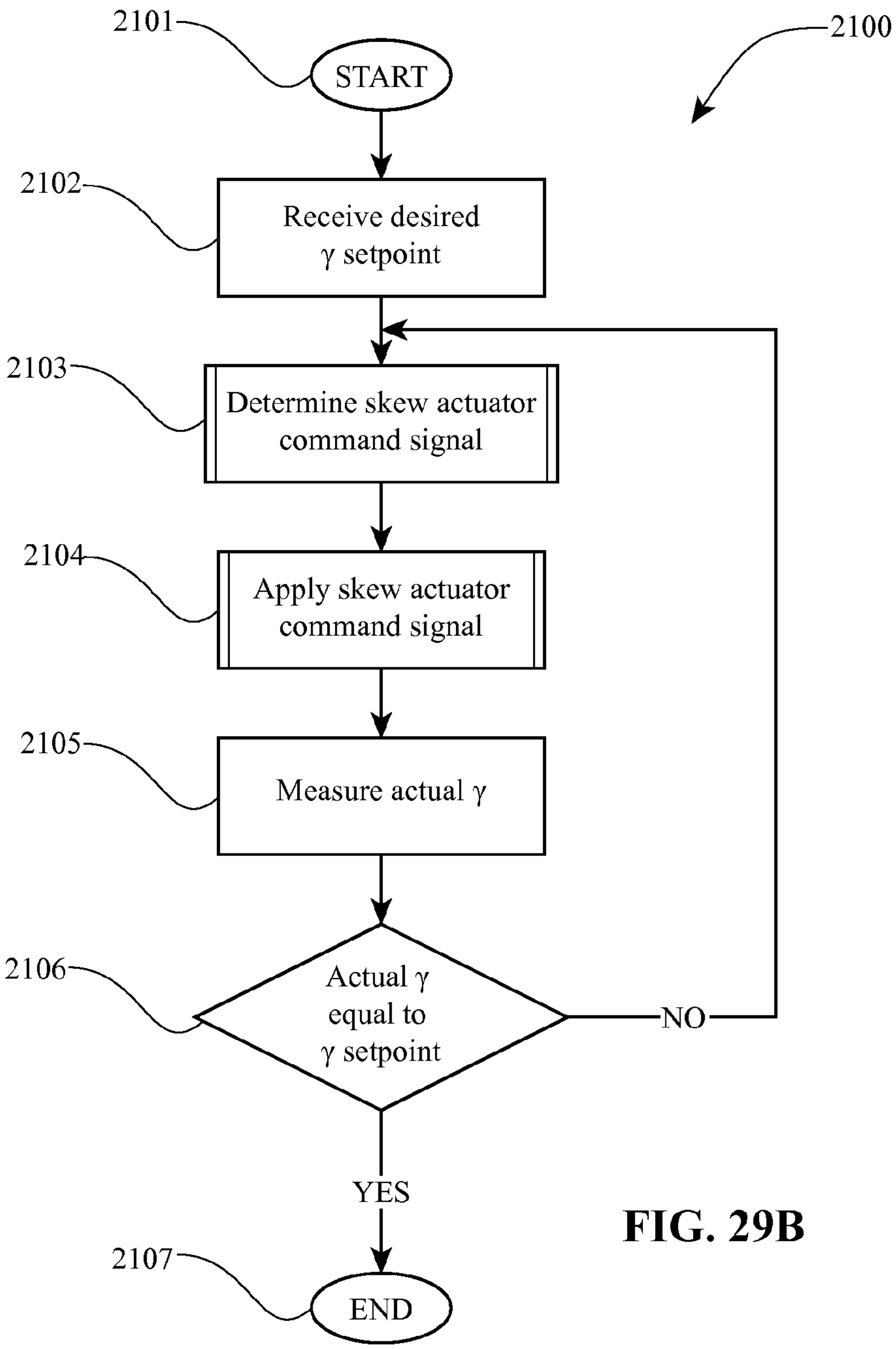

2100
2101
START
2102
Receive desired
γ setpoint
2103
Determine skew actuator
command signal
2104
Apply skew actuator
command signal
2105
Measure actual γ
2106
Actual γ
equal to
γ setpoint
NO
YES
2107
END

FIG. 29B

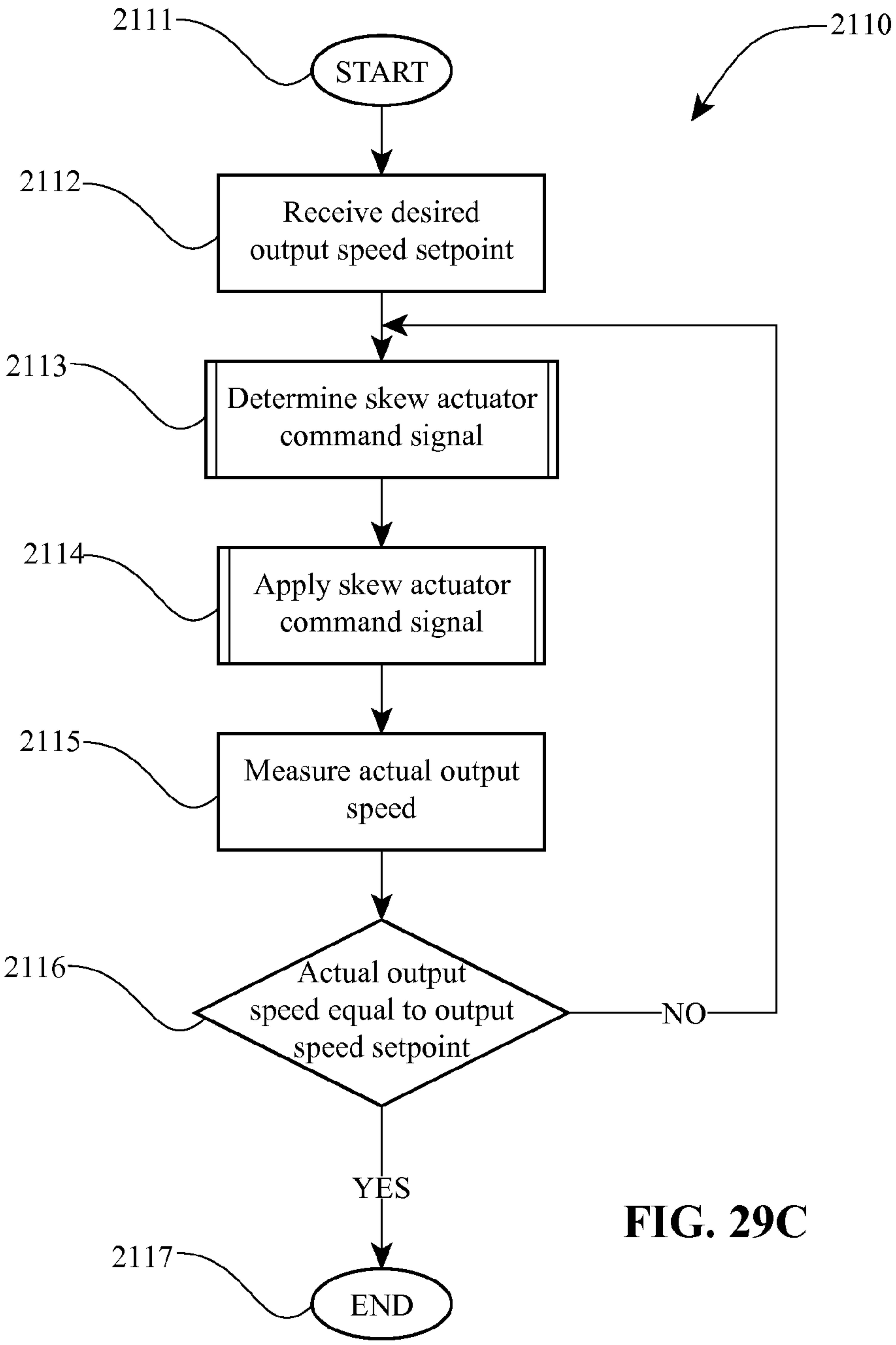

2110
2111
START
2112
Receive desired output speed setpoint
2113
Determine skew actuator command signal
2114
Apply skew actuator command signal
2115
Measure actual output speed
2116
Actual output speed equal to output speed setpoint
NO
YES
2117
END

FIG. 29C

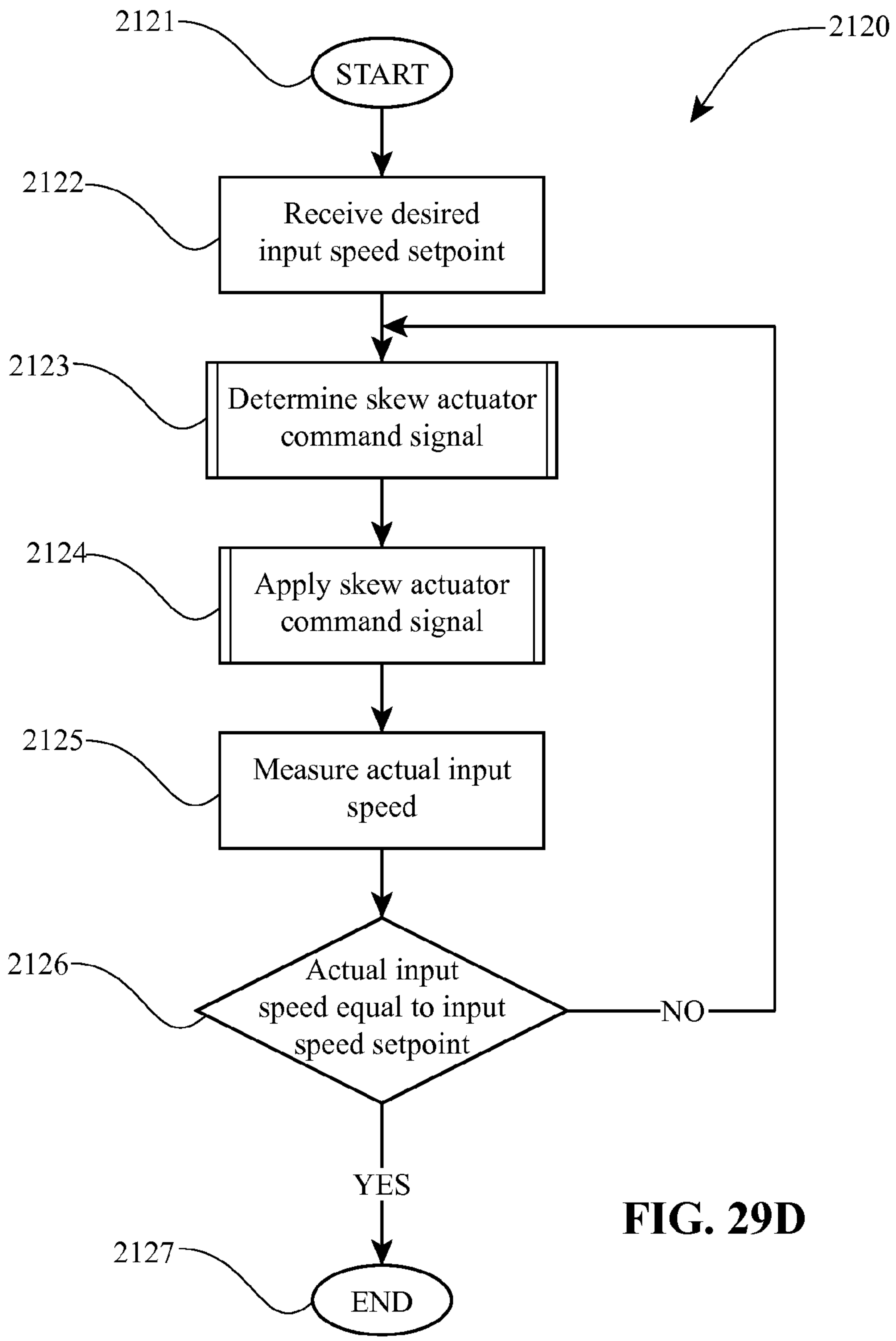

2120
2121
START
2122
Receive desired input speed setpoint
2123
Determine skew actuator command signal
2124
Apply skew actuator command signal
2125
Measure actual input speed
2126
Actual input speed equal to input speed setpoint
NO
YES
2127
END

FIG. 29D

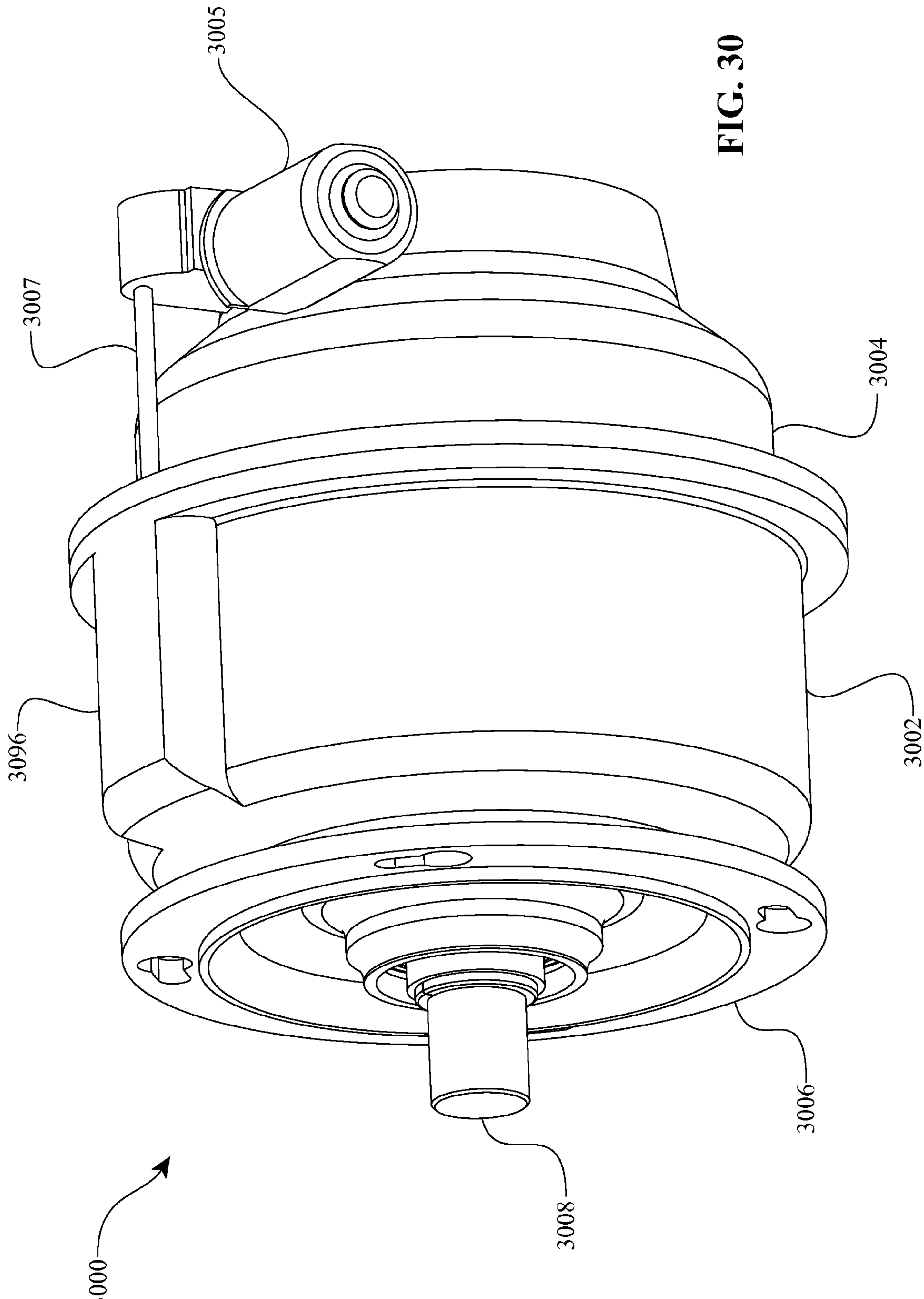


FIG. 30

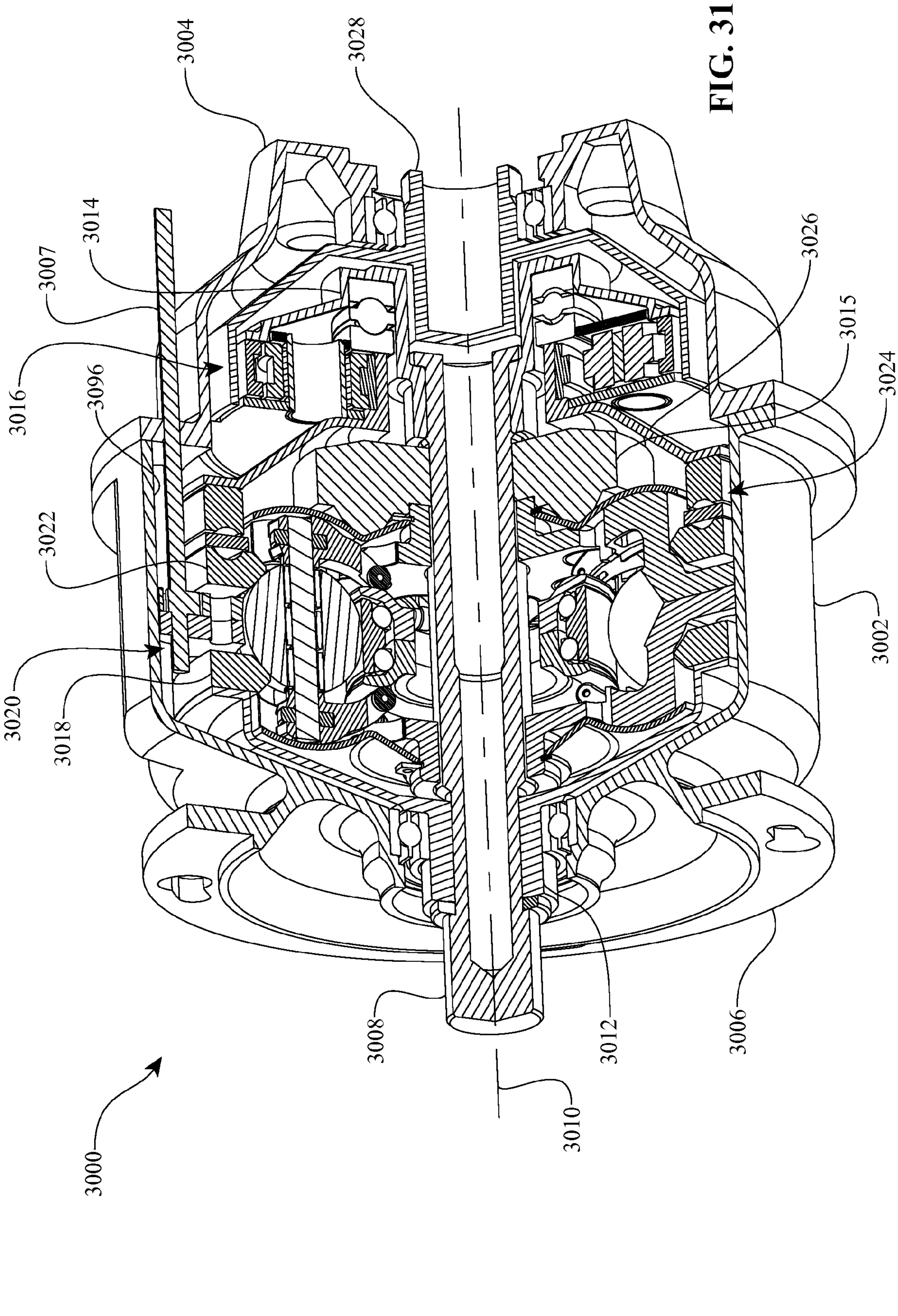

3004
3028
3014
3007
3016
3096
3022
3020
3018
3026
3015
3024
3002
3006
3012
3010
3008
3000

FIG. 31

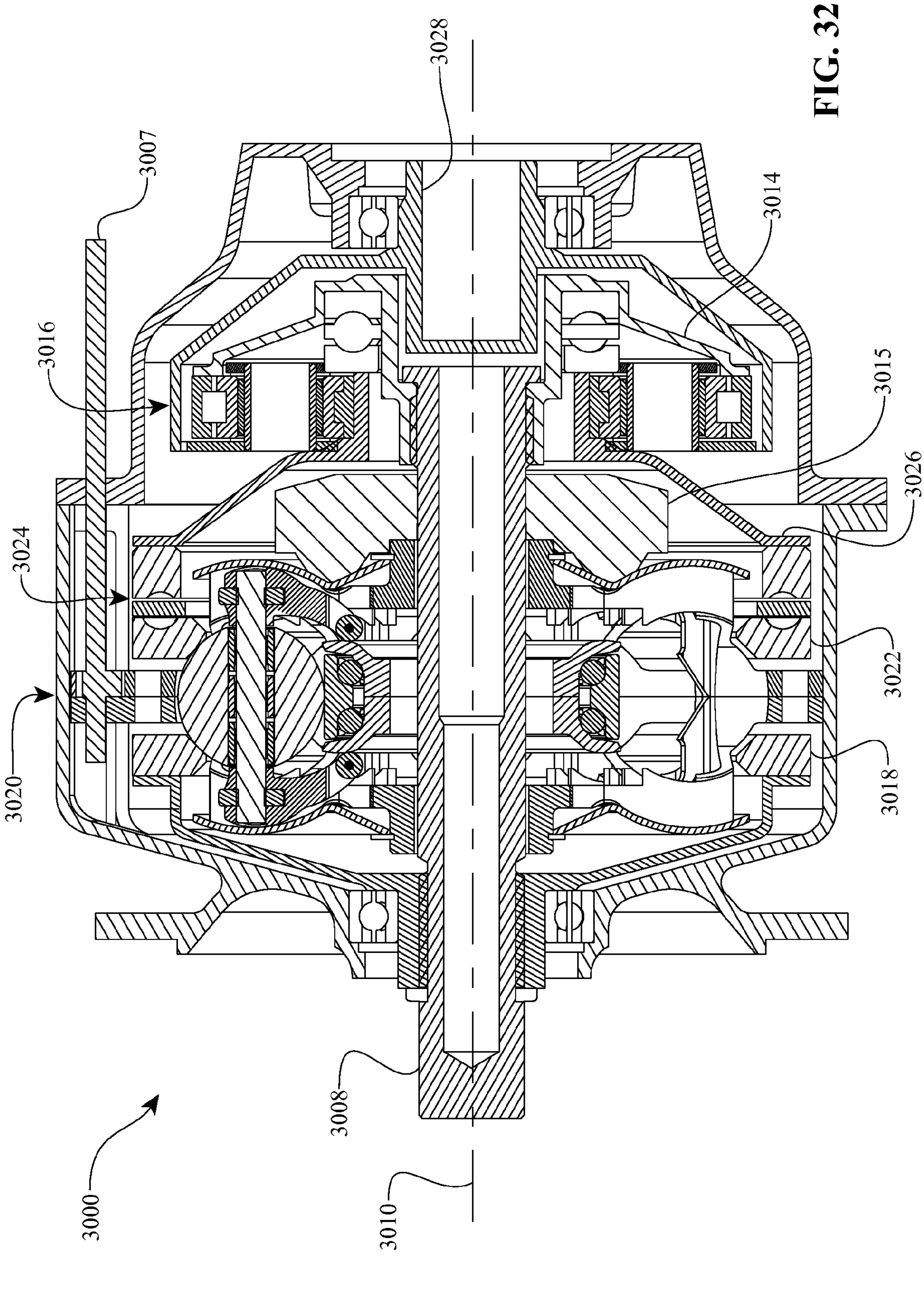

3028
3007
3014
3016
3015
3026
3024
3022
3020
3018
3008
3000
3010

FIG. 32

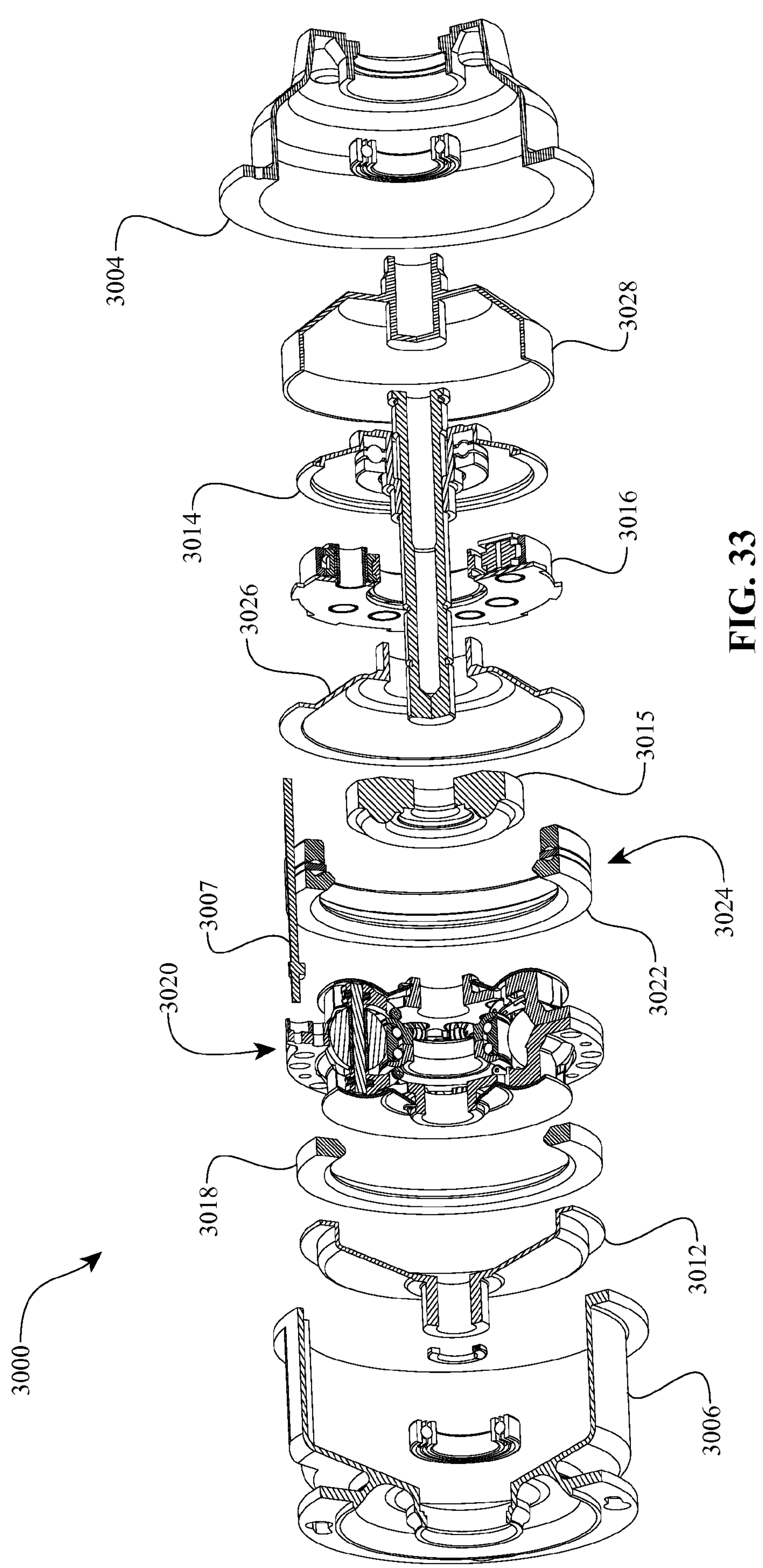
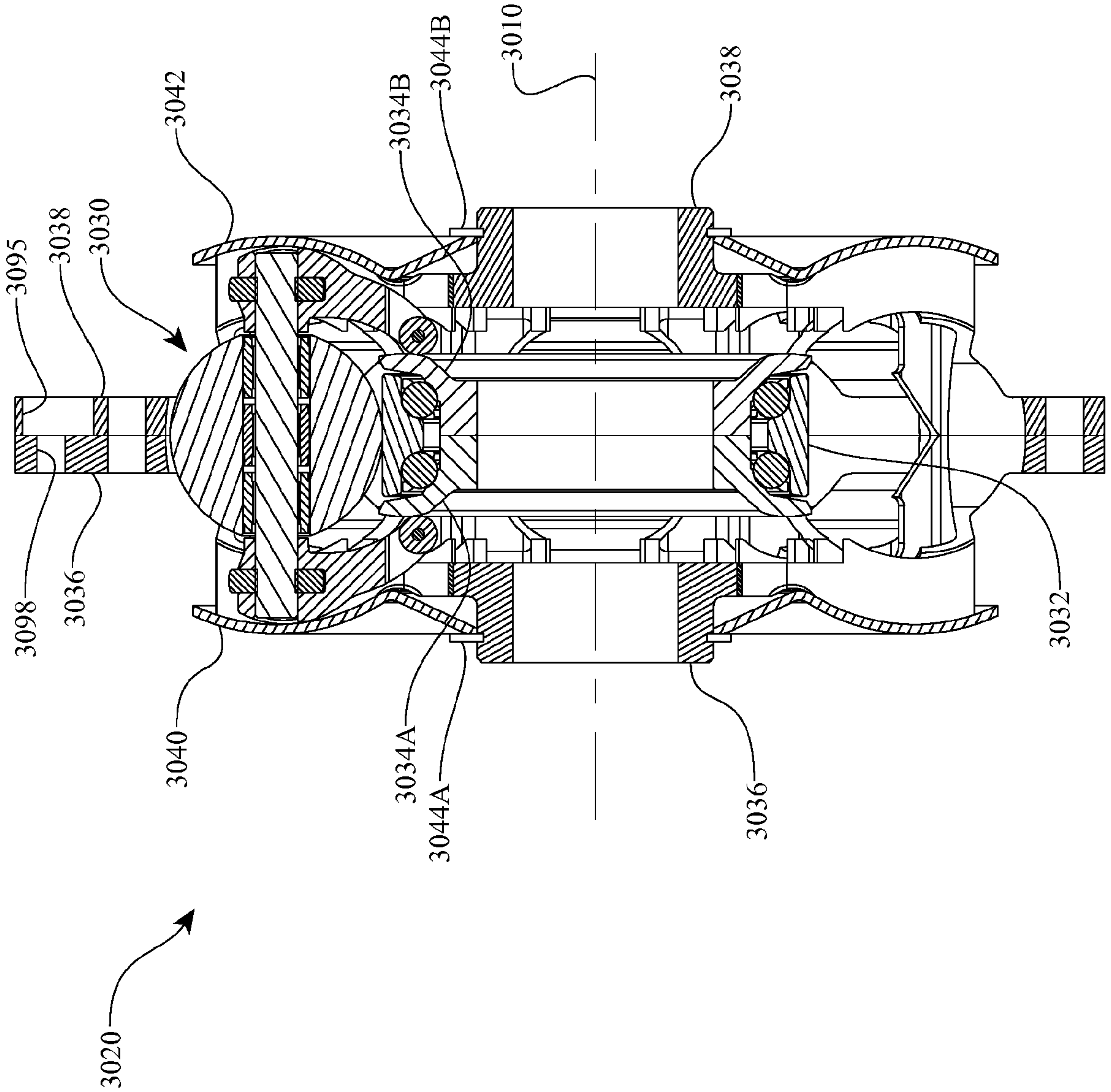

3004
3028
3014
3016
3026
3015
3007
3024
3022
3020
3018
3012
3000
3006

FIG. 33

FIG. 34


3095
3038
3030
3042
3034B
3044B
3010
3038
3098
3036
3040
3034A
3044A
3036
3032
3020

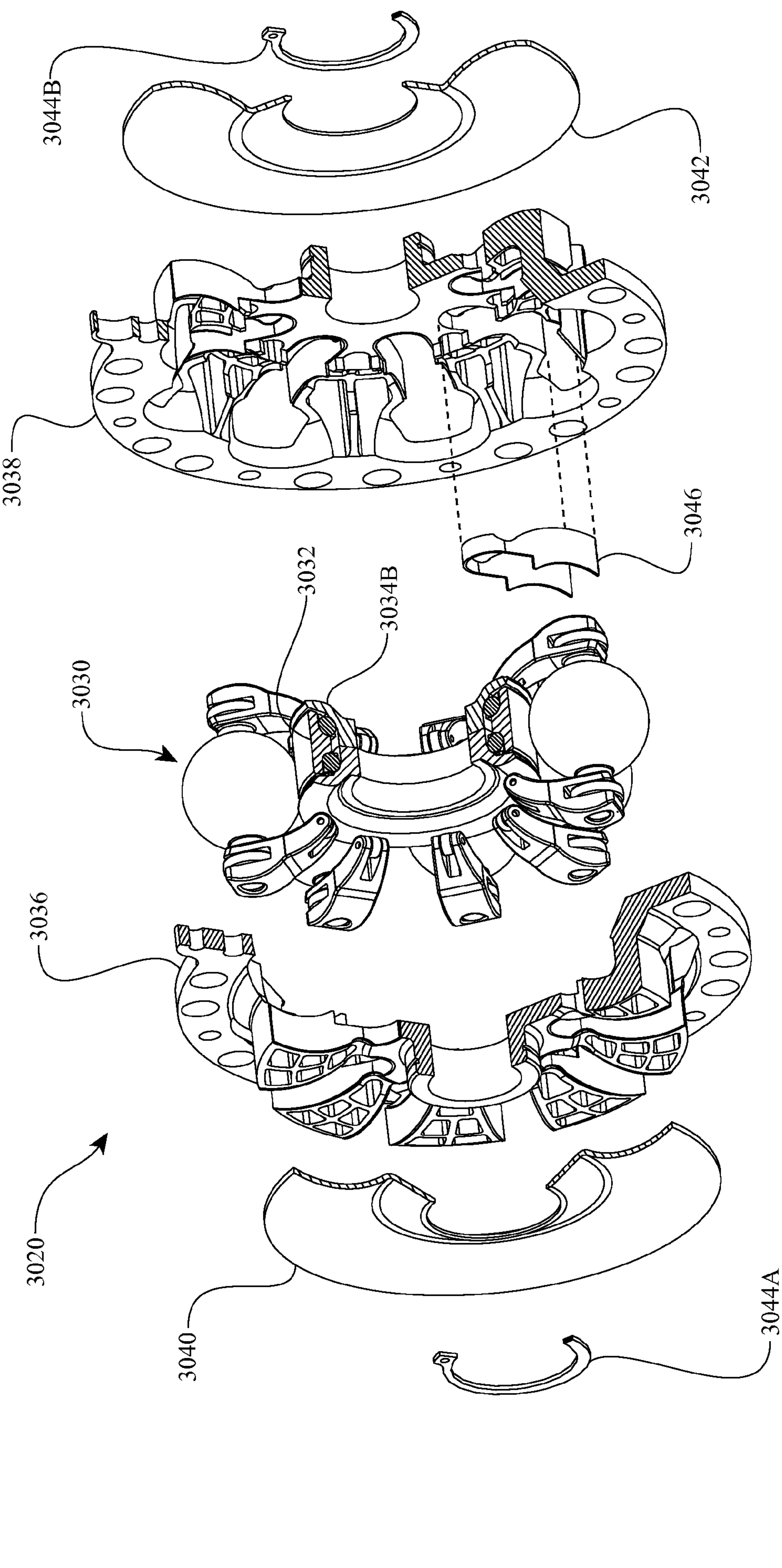


FIG. 35

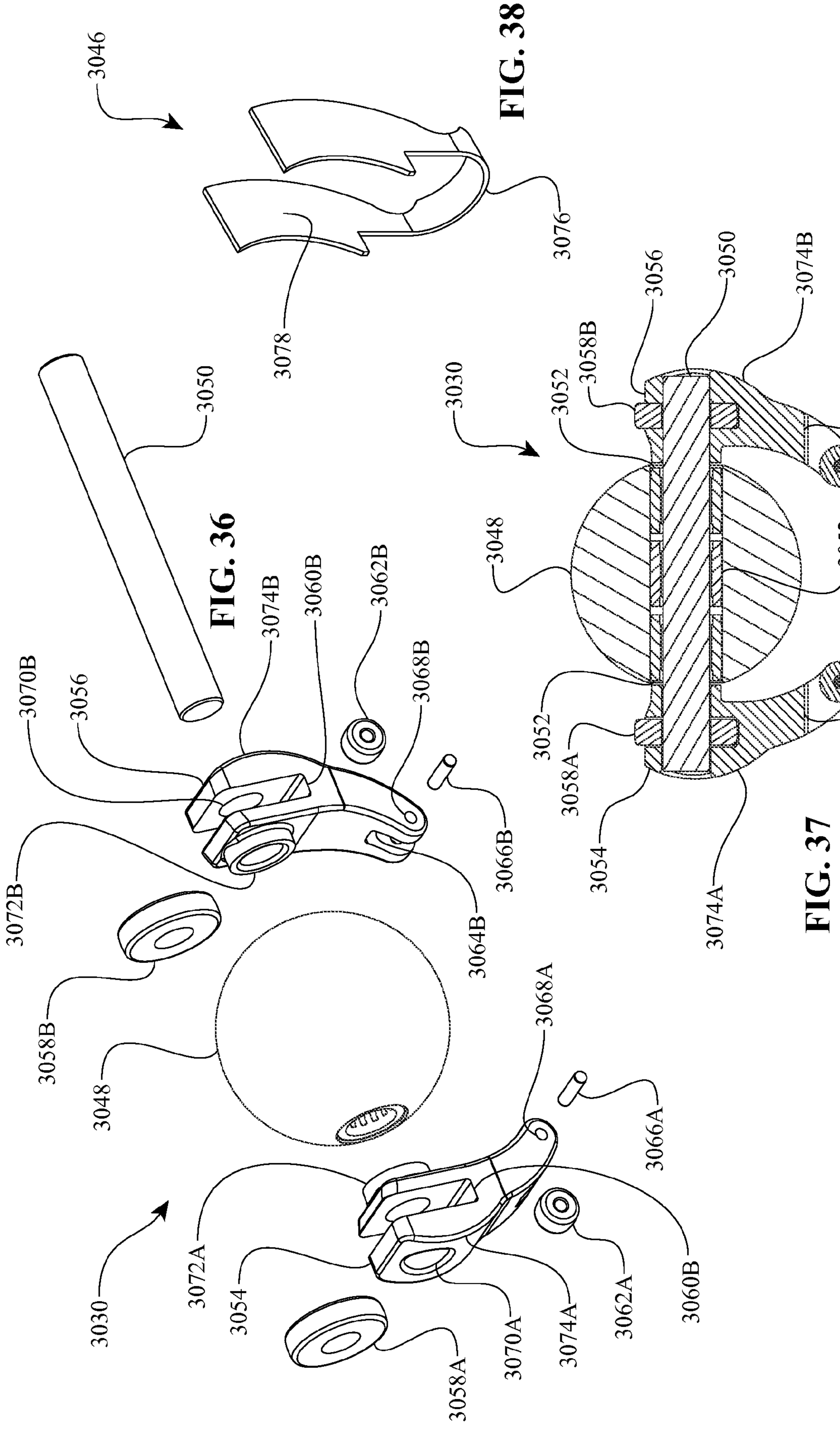


FIG. 38

FIG. 36

FIG. 37

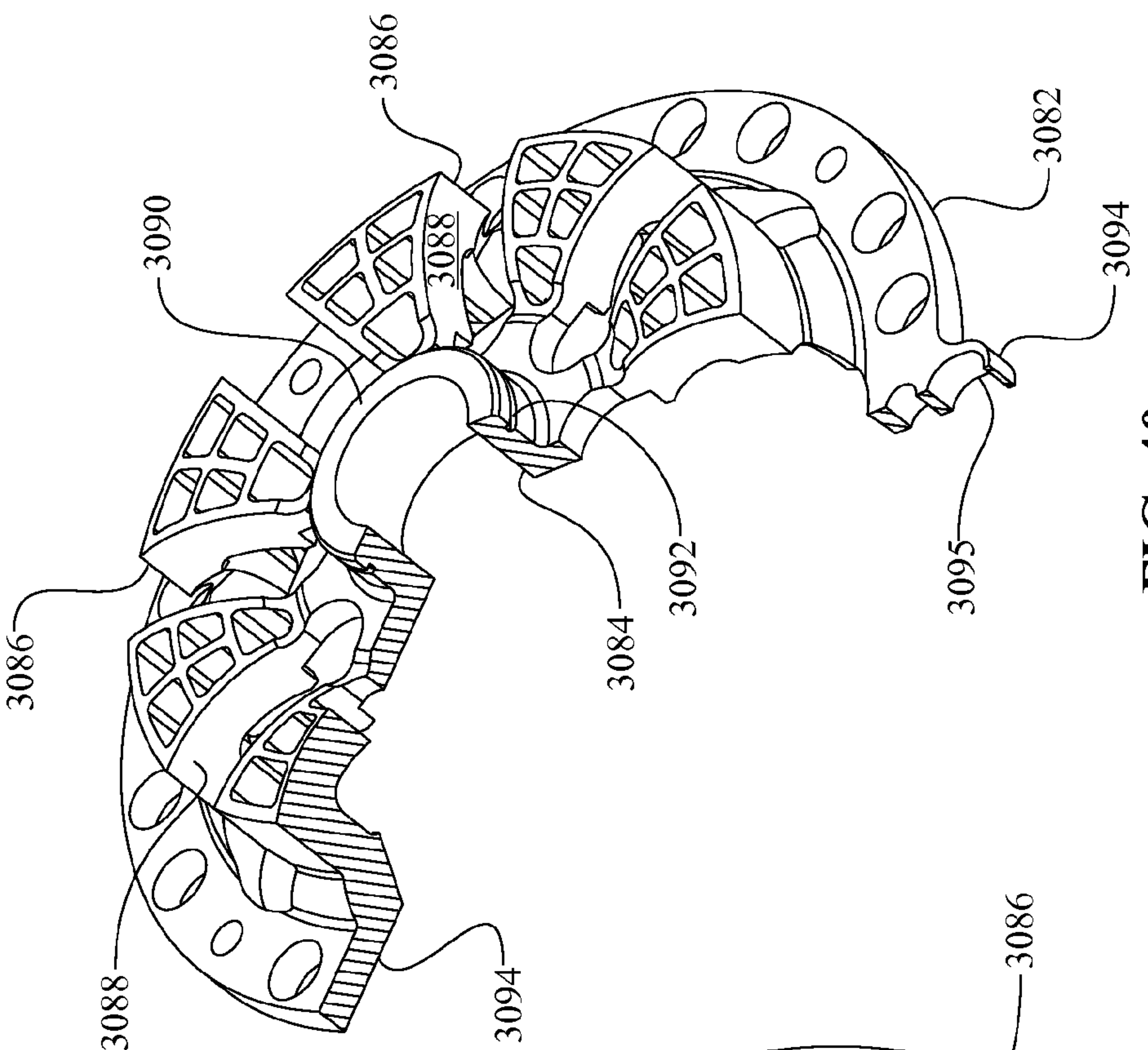

3086
3090
3088
3082
3094
3086
3084
3092
3095
3088
3094

FIG. 40

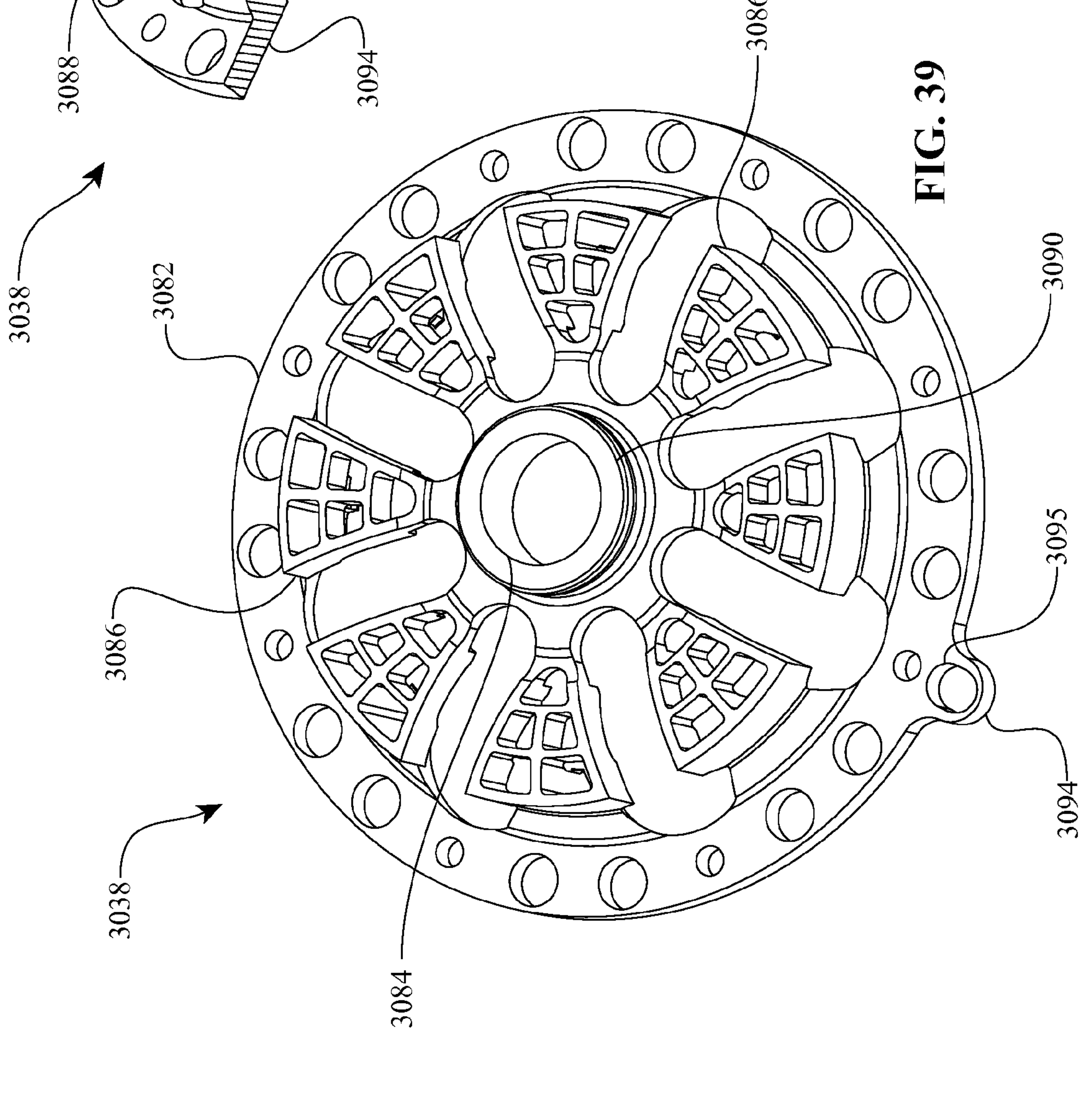

3038
3082
3086
3090
3086
3095
3094
3038
3084

FIG. 39

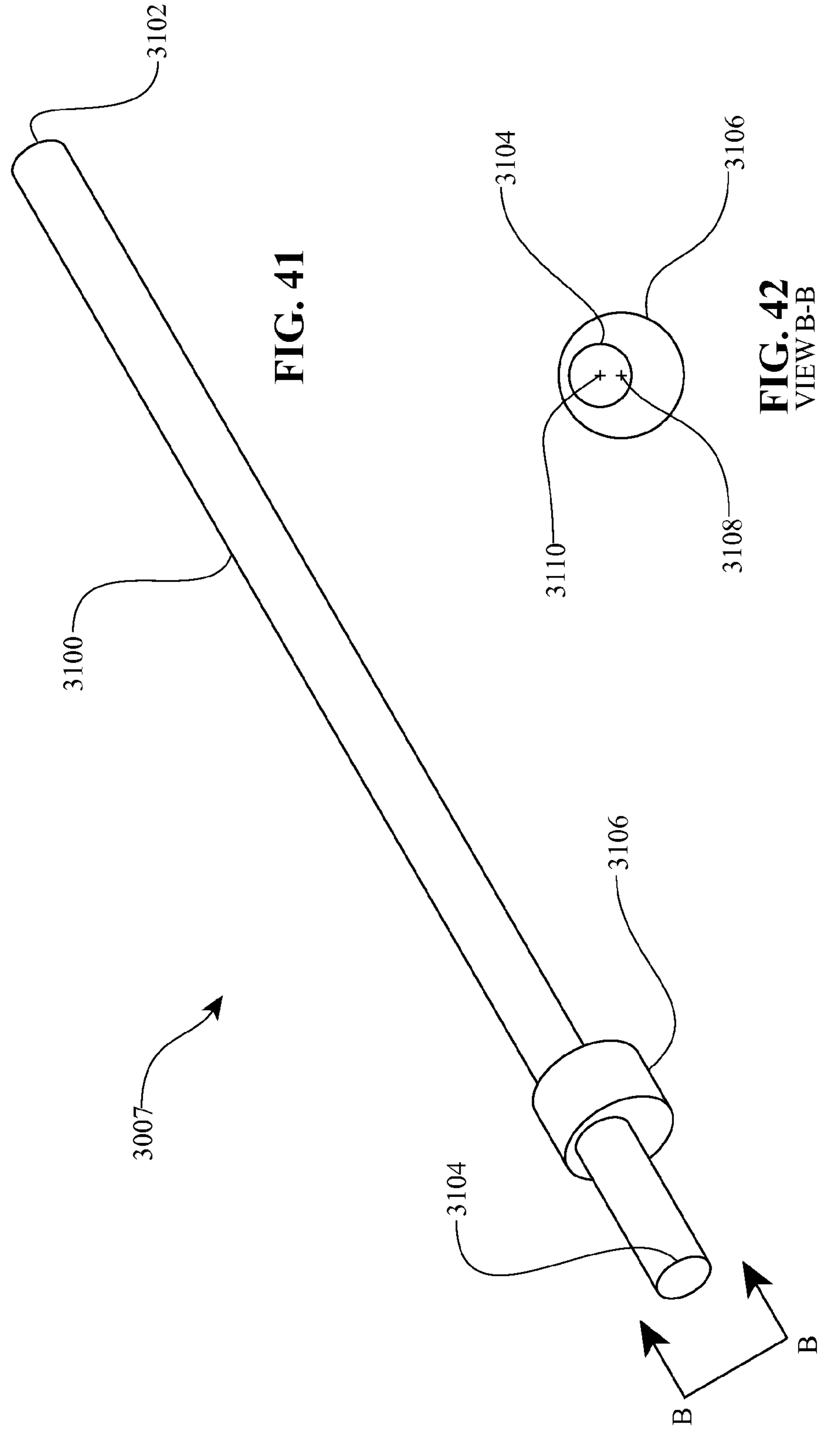


FIG. 41

FIG. 42
VIEW B-B

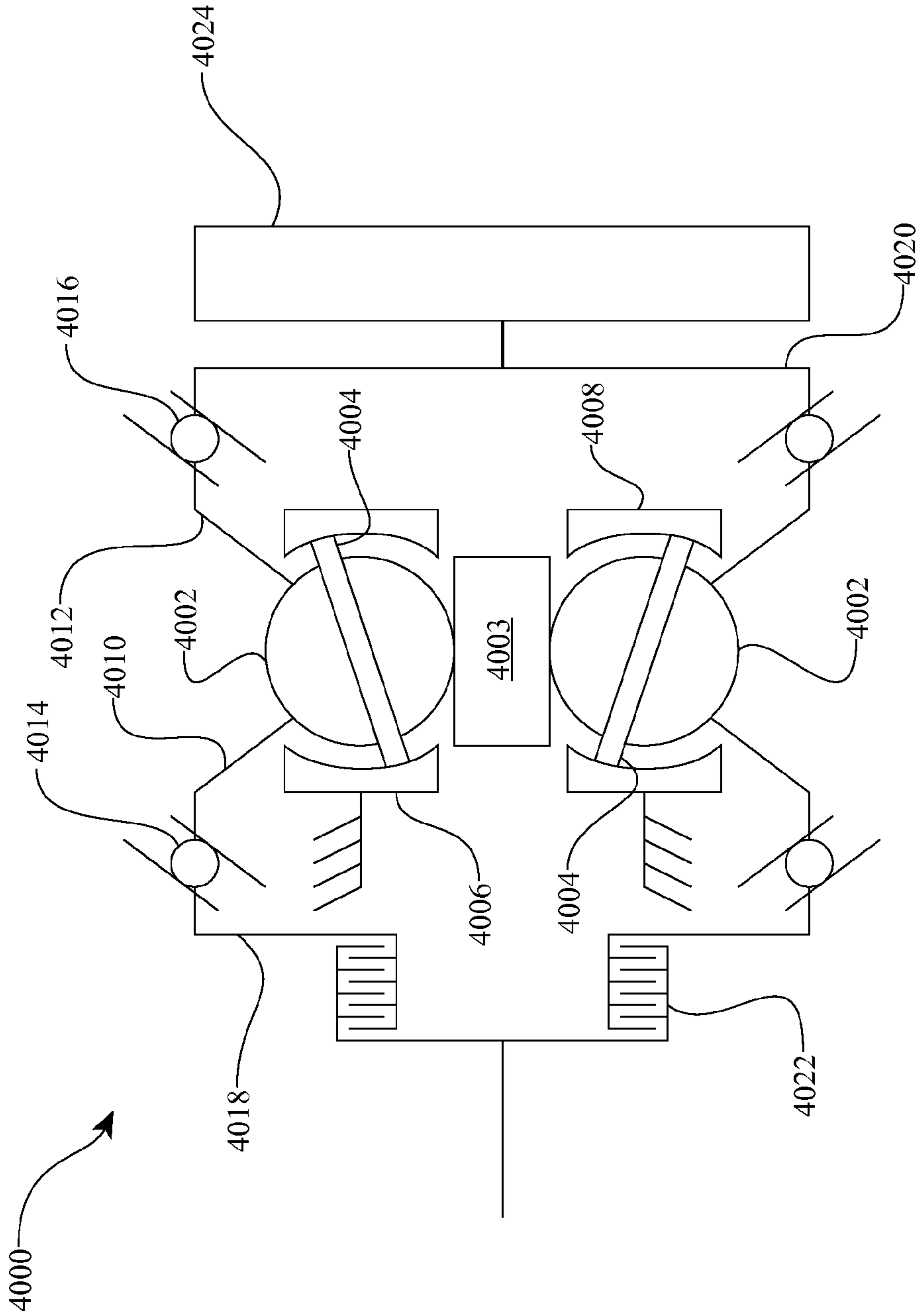

4024
4016
4020
4004
4008
4012
4002
4003
4002
4010
4014
4006
4004
4018
4022
4000

FIG. 43

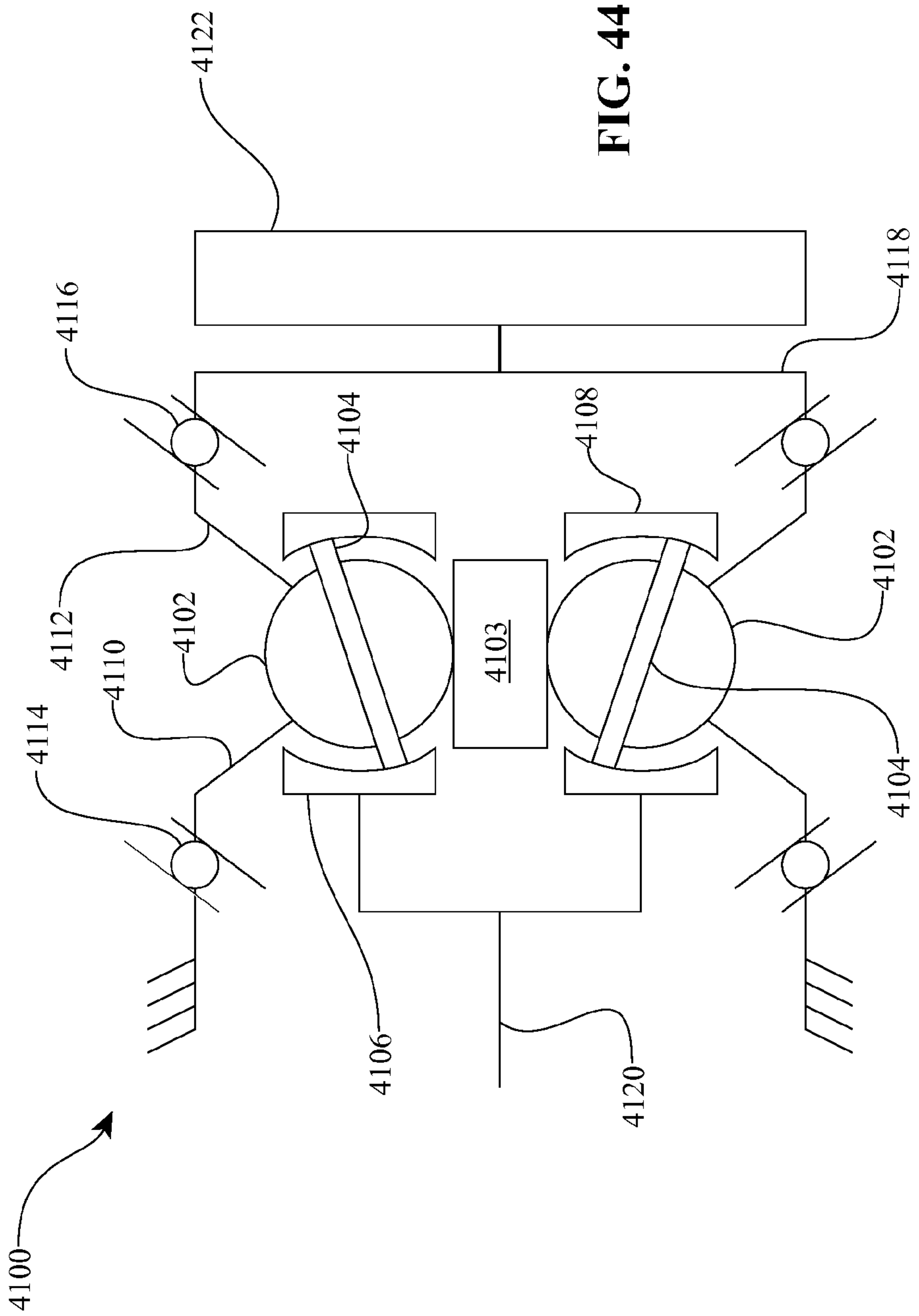
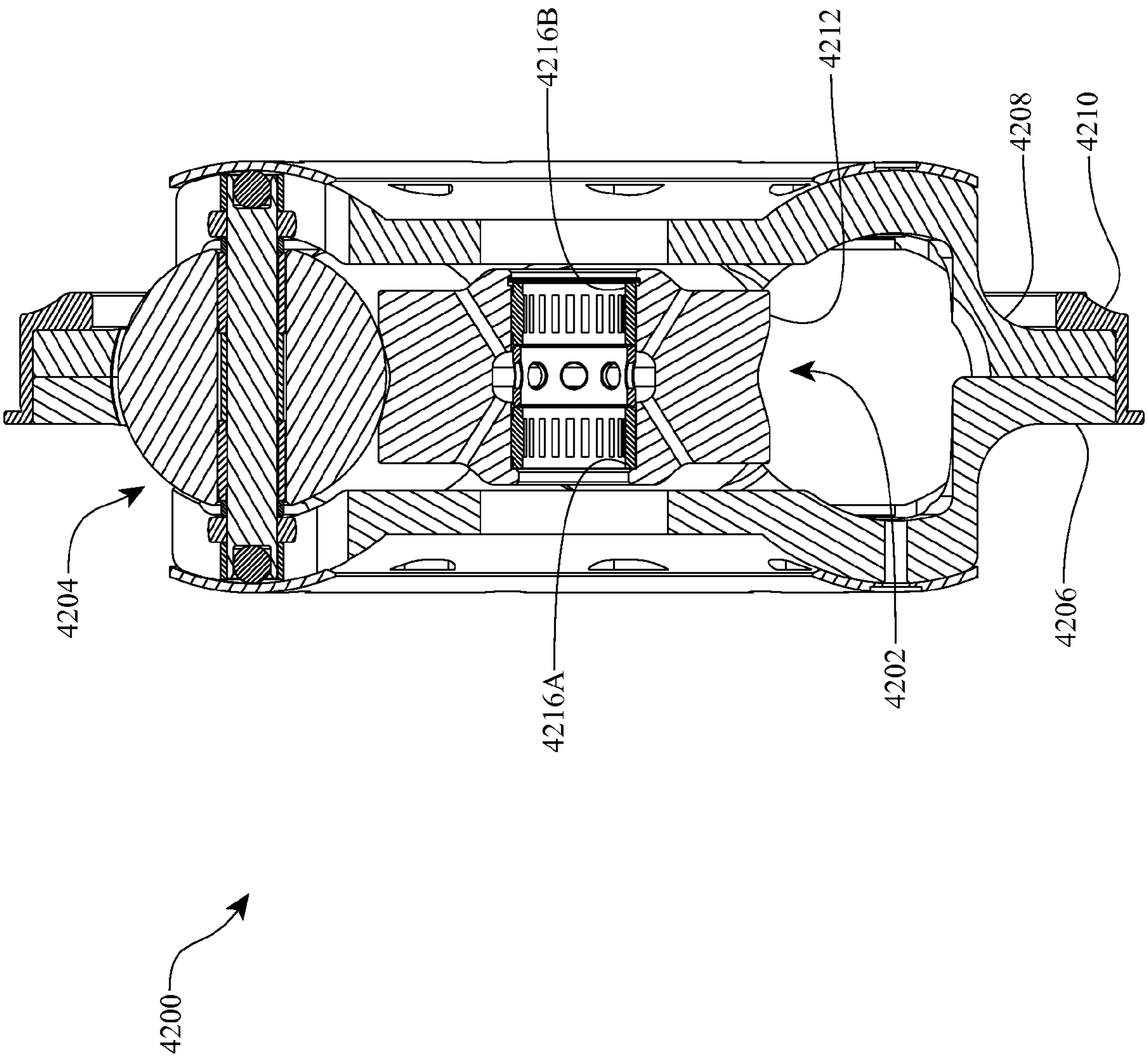

4122
4116
4118
4104
4108
4112
4110
4102
4103
4102
4114
4104
4106
4120
4100

FIG. 44

FIG. 45



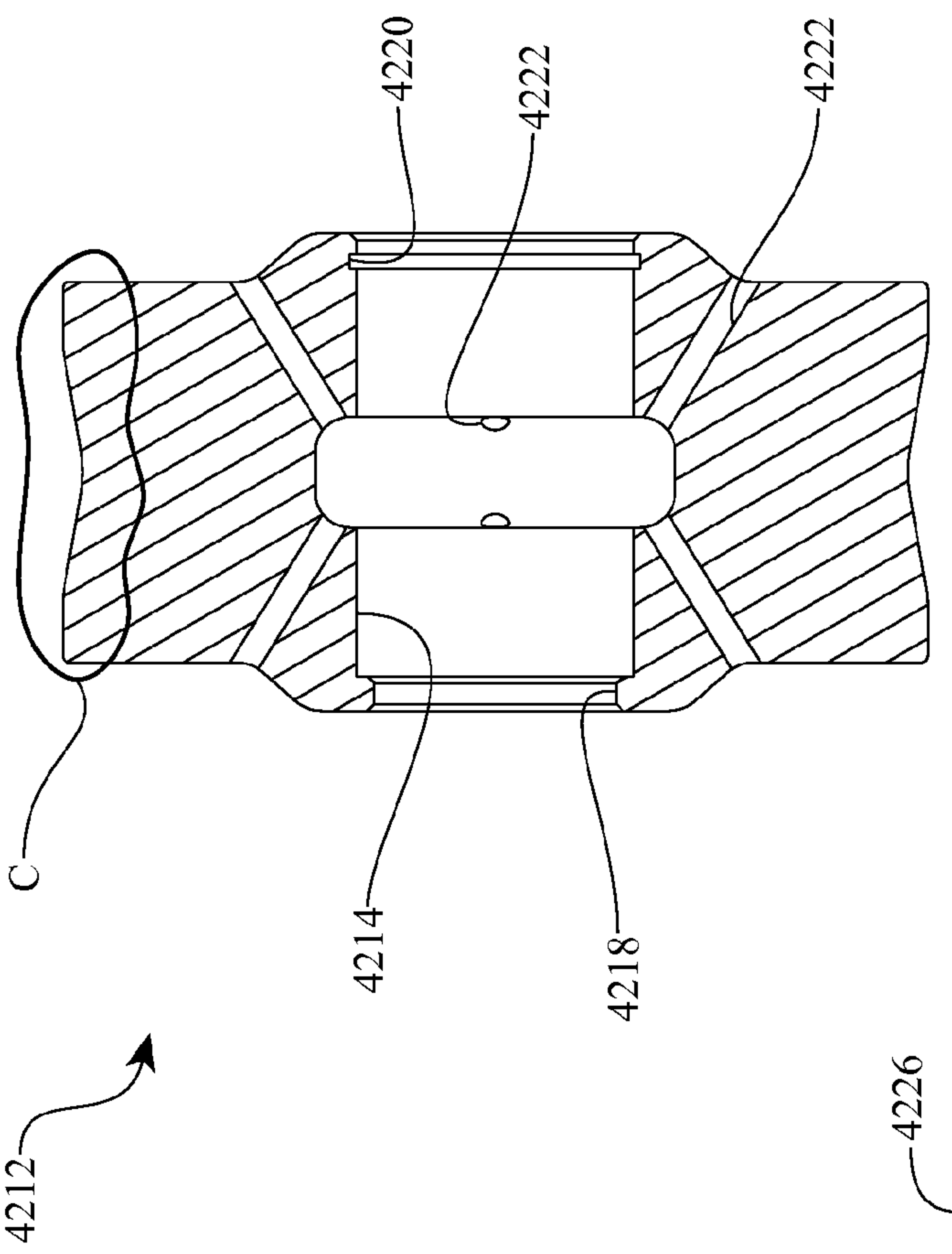


FIG. 47

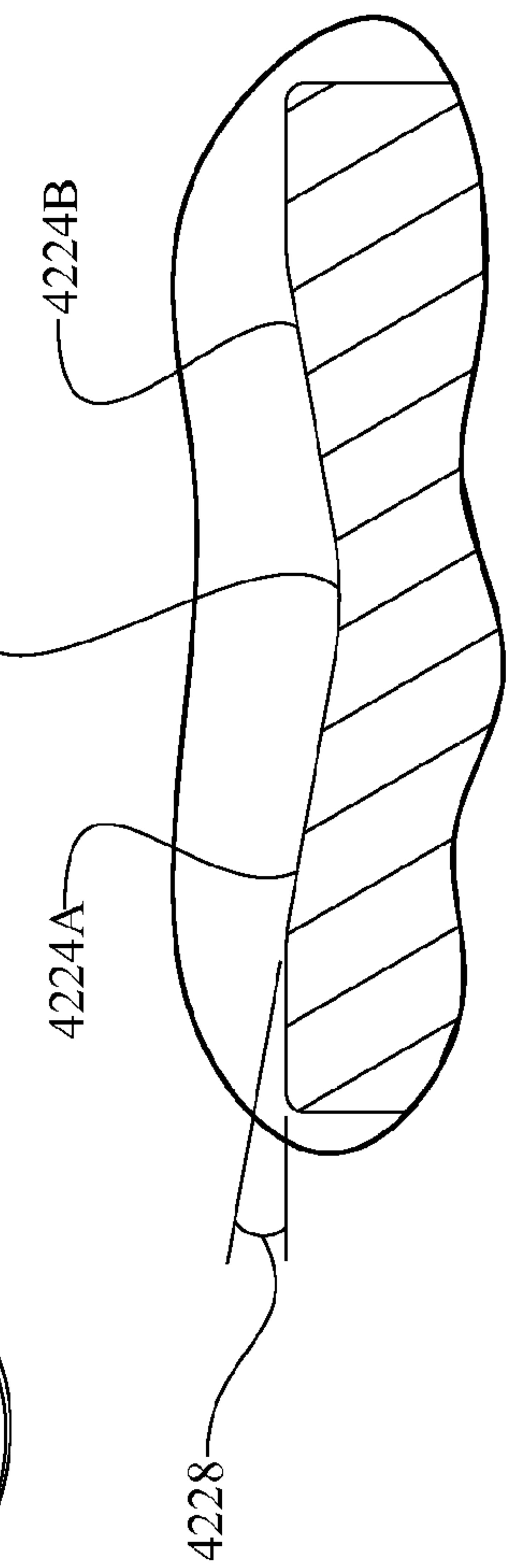


FIG. 48
DETAIL C

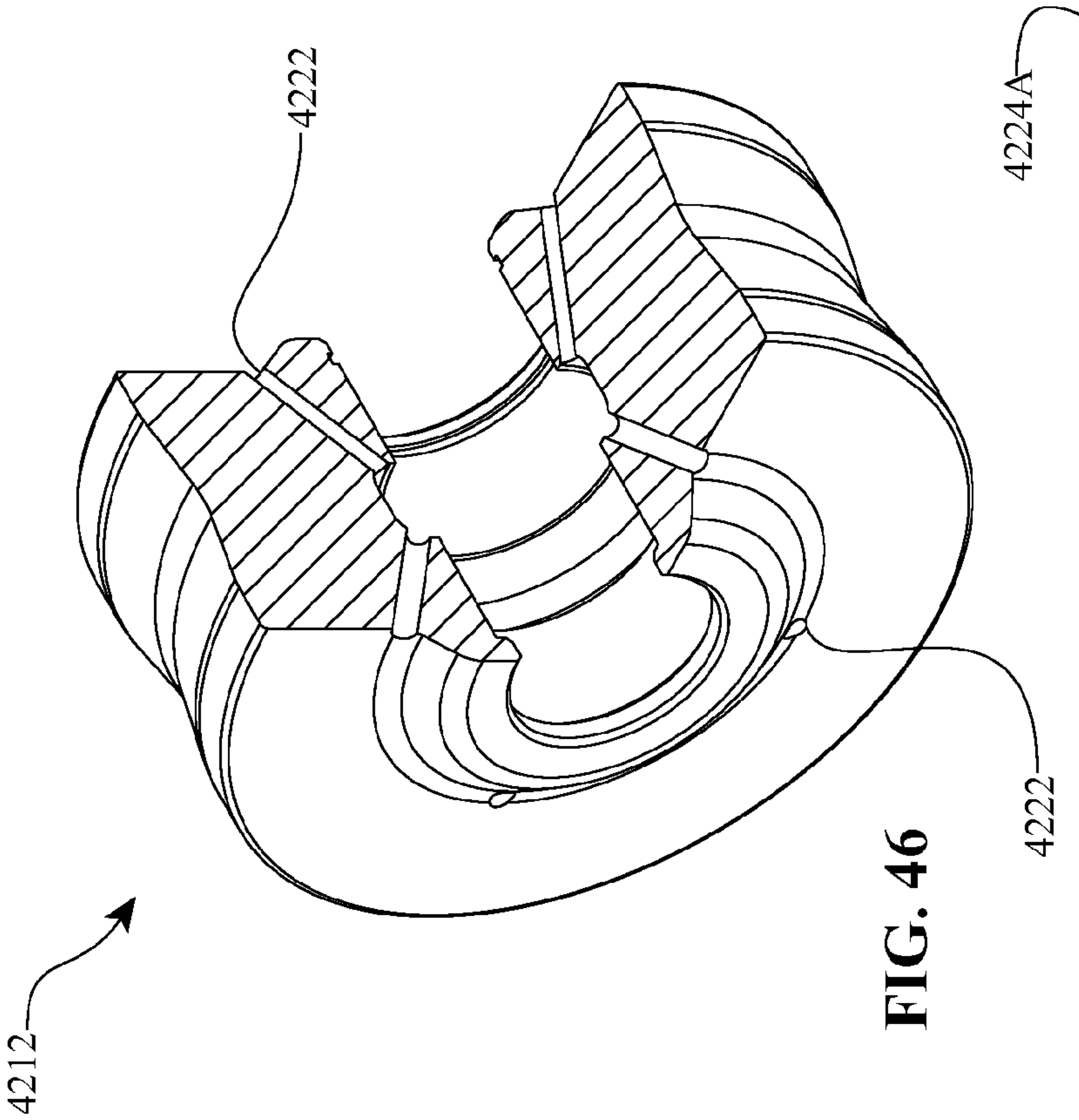


FIG. 46

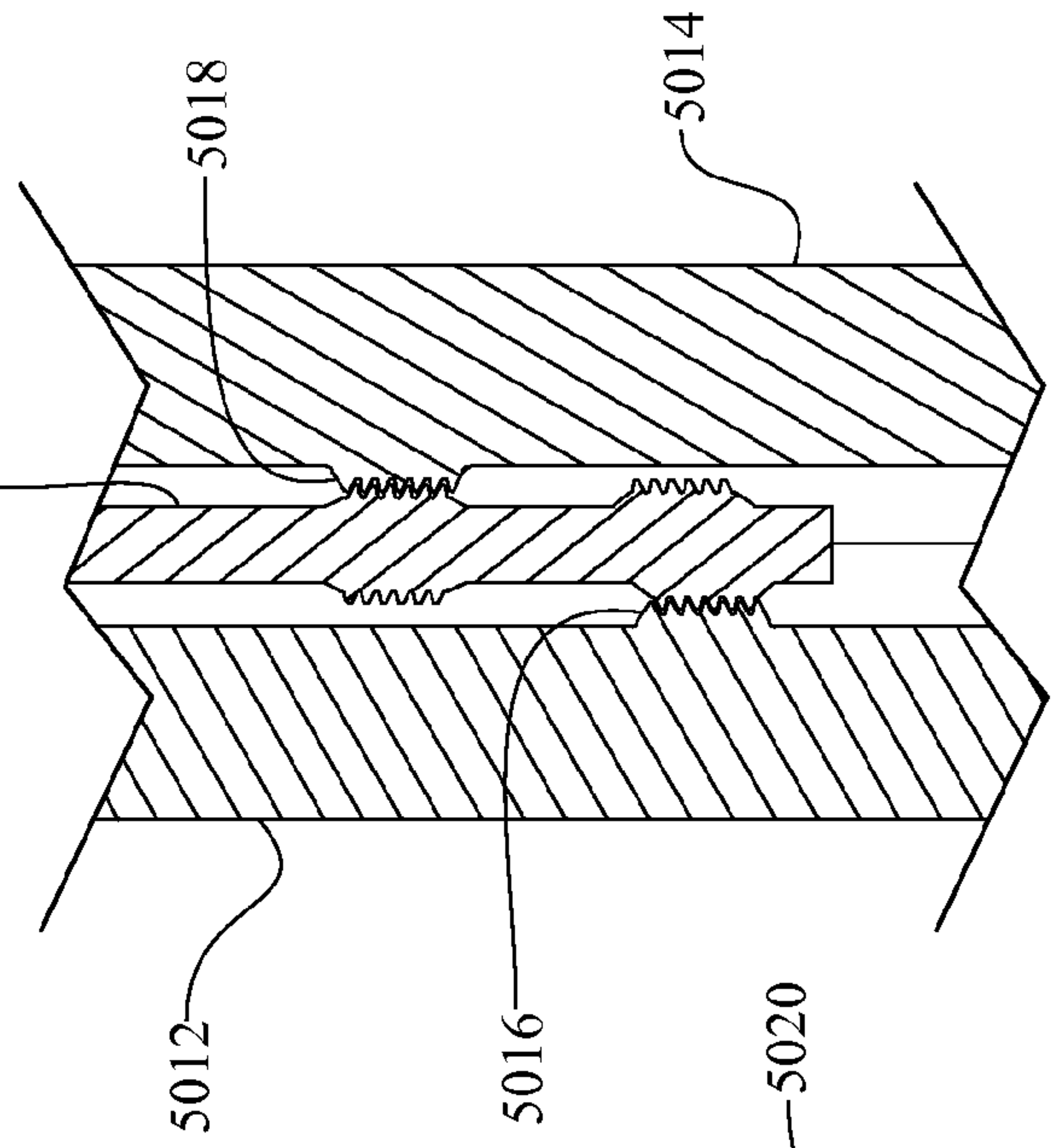


FIG. 51
VIEW C-C

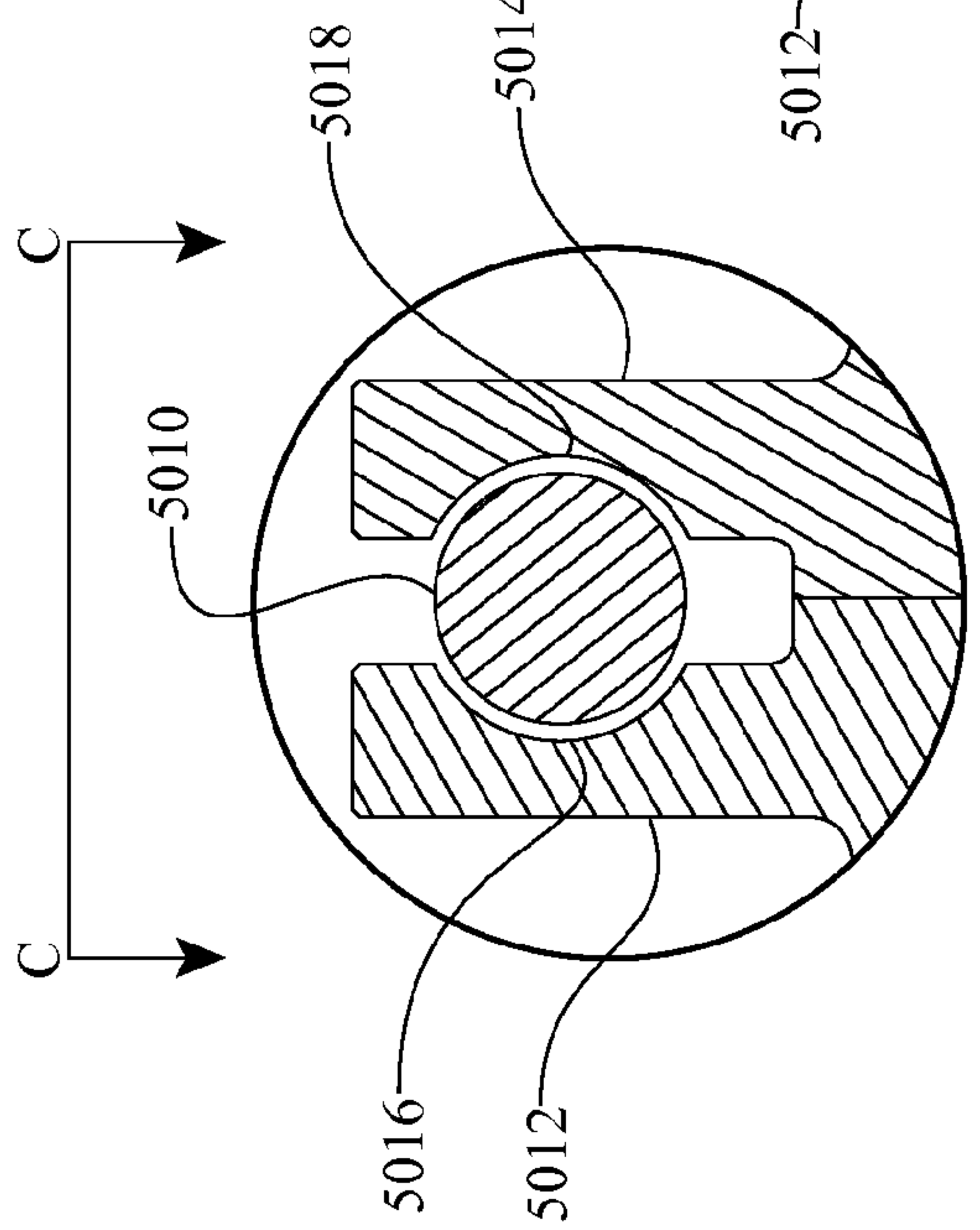


FIG. 50

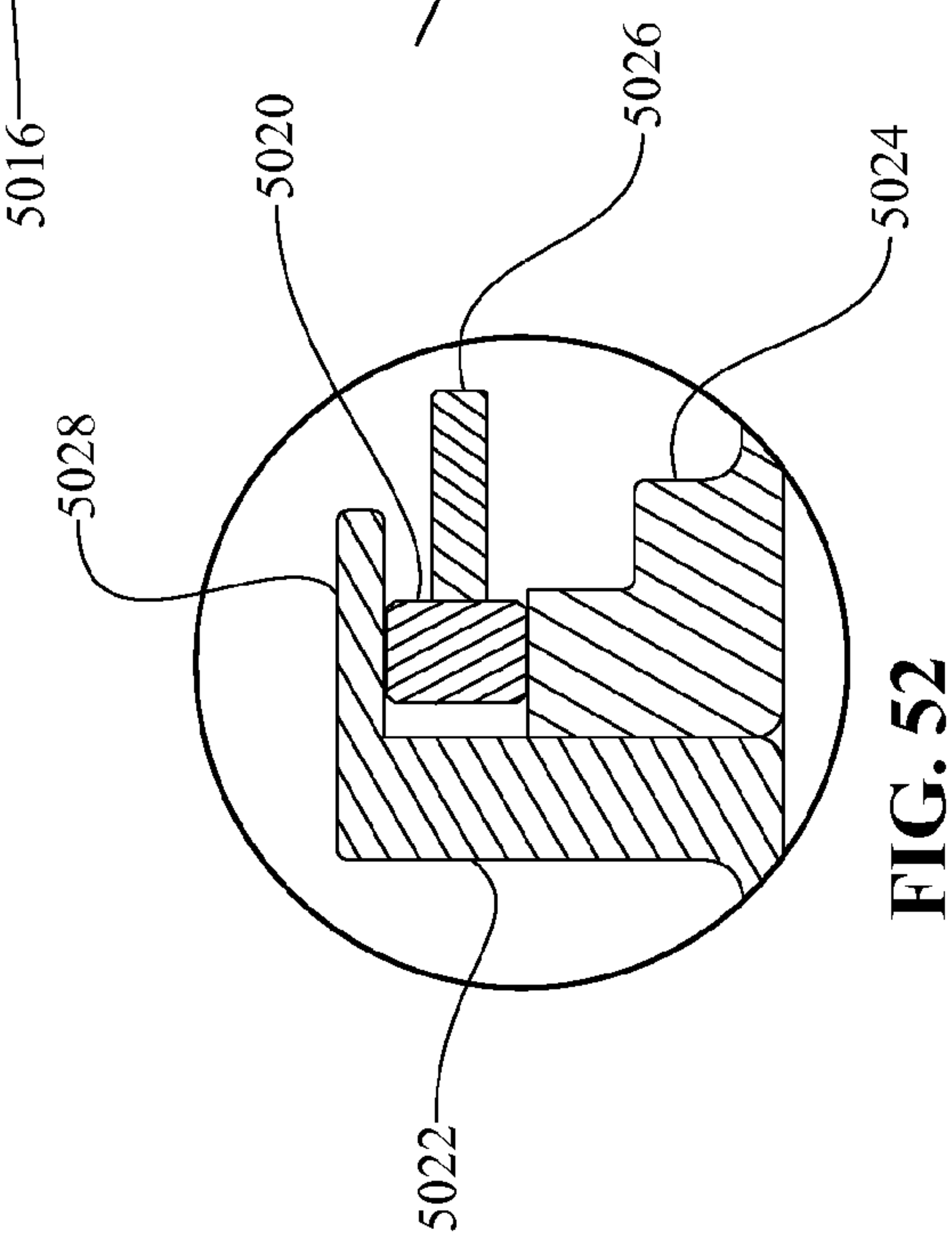


FIG. 52

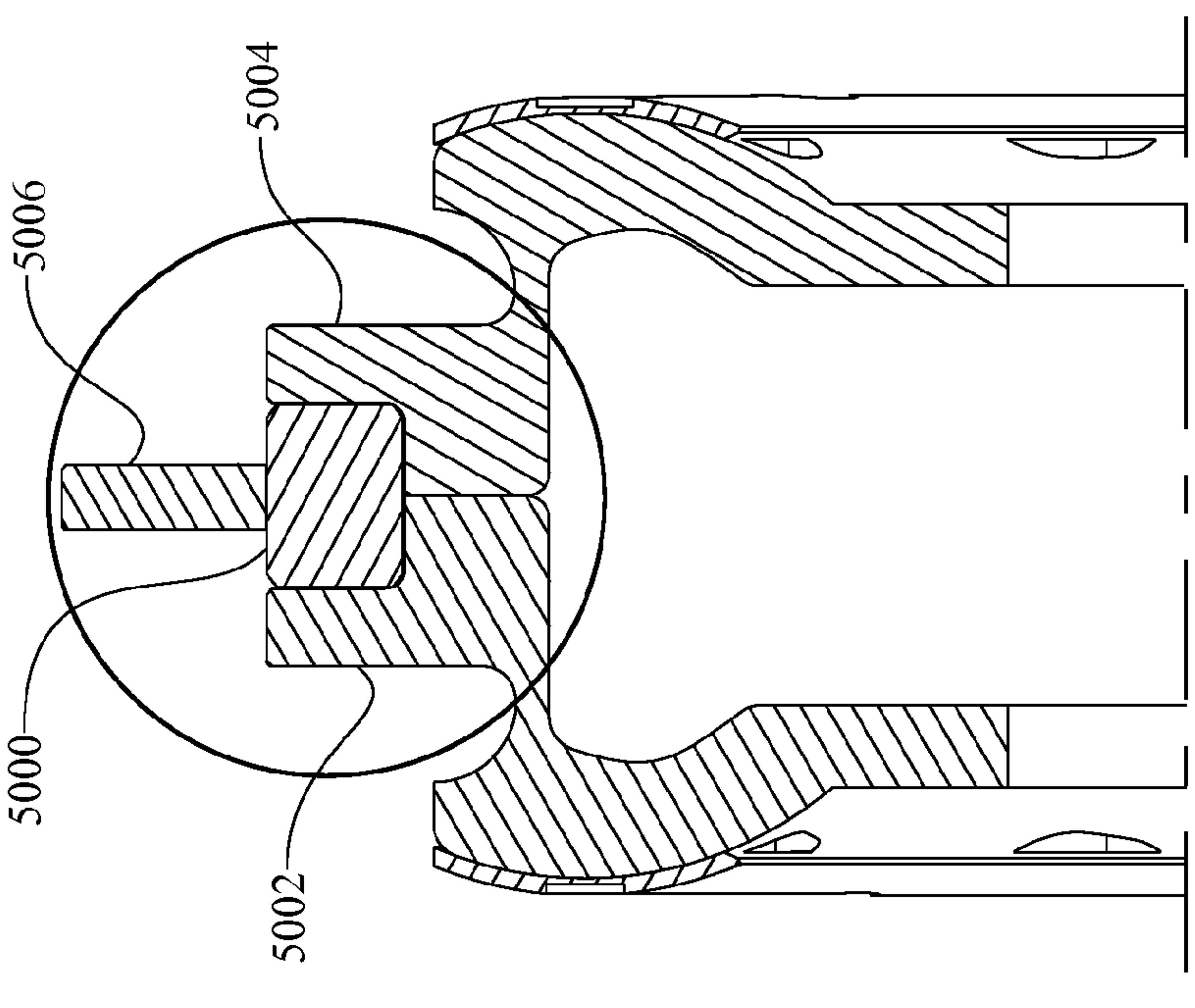
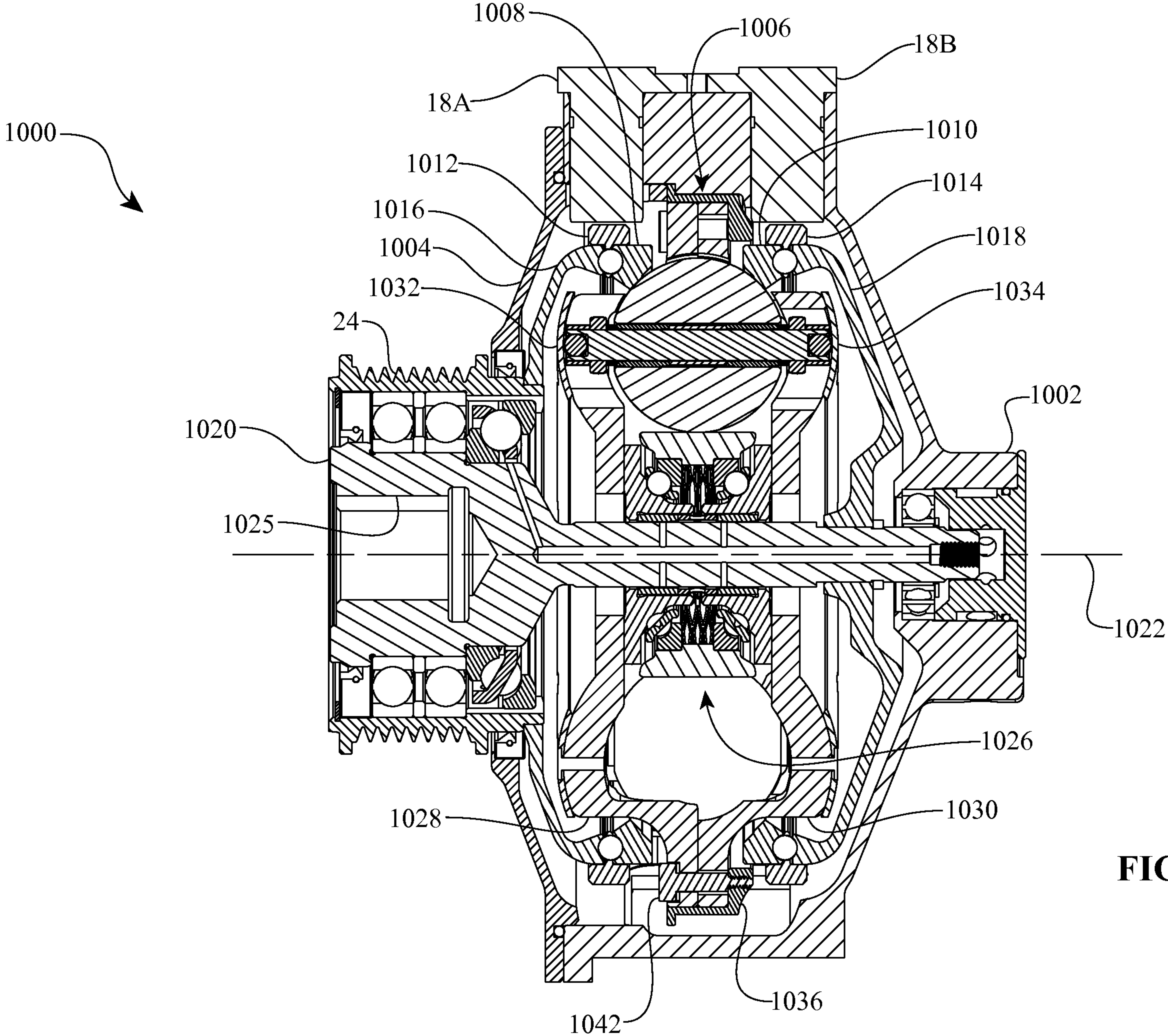


FIG. 49



1000
1008
1006
18B
18A
1010
1012
1014
1016
1018
1004
1032
1034
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1002
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1042

FIG. 15