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(54) **Title:** CARRIER SKEW SHIFT ACTUATOR MECHANISM FOR A CONTINUOUSLY VARIABLE BALL PLANETARY TRANSMISSION HAVING A ROTATING CARRIER

(57) **Abstract:** A continuously variable ball planetary transmission (CVP) is provided with a ball variator assembly having a plurality of tilttable balls supported in a carrier assembly. In some embodiments, the carrier assembly is configured to be rotatable. A carrier skew shift actuator mechanism is configured to provide a means for adjusting the relative position of a first carrier member to a second carrier member of the carrier assembly to thereby adjust the operation of the infinitely variable transmission. Devices and methods are provided herein for the transmission of power through the CVP.



**CARRIER SKEW SHIFT ACTUATOR MECHANISM FOR A CONTINUOUSLY
VARIABLE BALL PLANETARY TRANSMISSION HAVING A ROTATING
CARRIER**

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RELATED APPLICATION

The present application claims the benefit of U.S. Provisional Application No. 62/301,989 filed on March 1, 2016 which is incorporated herein by reference in its entirety.

BACKGROUND

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A driveline including a continuously variable transmission allows an operator or a control system to vary a drive ratio in a stepless manner, permitting a power source(s) to operate at its most advantageous rotational speed.

SUMMARY

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Provided herein is a carrier skew shift actuator mechanism for a continuously variable transmission (CVT) having a plurality of tiltable balls supported by a first carrier member and a second carrier member, each ball in contact with a first traction ring assembly and a second traction ring assembly, the carrier skew shift actuator mechanism including: a first helical gear coupled to the first carrier member; a second helical gear coupled to the second carrier member; and a driver shaft coupled to the first helical gear and the second helical gear; wherein the driver shaft is rotatable and adapted to translate axially.

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Provided herein is a continuously variable transmission having a plurality of tiltable balls arrayed radially about a longitudinal axis of the transmission; a first carrier member having a first plurality of guide slots, the tiltable balls operably coupled to the first plurality of guide slots; a second carrier member having a second plurality of guide slots, the tiltable balls operably coupled to the second plurality of guide slots, wherein the second plurality of guide slots are radially offset from the first plurality of guide slots; a first traction ring assembly in contact with each tiltable ball; a second traction ring assembly in contact with each tiltable ball; and a carrier skew shift actuator mechanism comprising: a first helical gear coupled to the first carrier member; a second helical gear coupled to the second carrier member; and a driver shaft coupled to the first helical gear and the second helical gear.

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Provided herein is a hybrid powertrain including: an internal combustion engine, a first motor-generator; a second motor-generator; a third motor-generator; a fourth motor-generator; a first

planetary gear set having a first sun gear, a first planet carrier, a second sun gear, a first planet gear and a second planet gear; a second planetary gear set having a third sun gear, a second planet carrier, a fourth sun gear, a third planet gear and a fourth planet gear; wherein the first motor-generator is coupled to the first sun gear; wherein the second motor-generator is coupled to the first planet carrier; wherein the fourth motor-generator is coupled to the fourth sun gear; a continuously variable transmission including a plurality of tiltable balls arrayed radially about a longitudinal axis of the transmission; a first carrier member having a first plurality of guide slots, the tiltable balls operably coupled to the first plurality of guide slots; a second carrier member having a second plurality of guide slots, the tiltable balls operably coupled to the second plurality of guide slots, wherein the second plurality of guide slots are radially offset from the first plurality of guide slots; a first traction ring assembly in contact with each tiltable ball, the first traction ring assembly coupled to the third sun gear; a second traction ring assembly in contact with each tiltable ball, the second traction ring assembly coupled to the second sun gear; and a carrier skew shift actuator mechanism including: a first helical gear coupled to the first carrier member; a second helical gear coupled to the second carrier member; and a driver shaft coupled to the first helical gear and the second helical gear, the driver shaft operably coupled to the third motor-generator.

INCORPORATION BY REFERENCE

All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of the preferred embodiments are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present embodiments will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the preferred embodiments are utilized, and the accompanying drawings of which:

Figure 1 is a side sectional view of a ball-type variator.

Figure 2 is a plan view of a carrier member that is used in the variator of Figure 1.

Figure 3 is an illustrative view of different tilt positions of the ball-type variator of Figure 1.

Figure 4 is a schematic diagram of a continuously variable transmission of the ball-type depicted in Figures 1-3 having a carrier skew shift actuator mechanism arranged radially outward of the first carrier and a shaft coupled to the carrier.

Figure 5 is a schematic diagram of a continuously variable transmission of the ball-type depicted in Figures 1-3 having a carrier skew shift actuator mechanism arranged radially outward of the first carrier and a shaft coupled to the sun.

Figure 6 is a schematic diagram of a continuously variable transmission of the ball-type depicted in Figures 1-3 having a carrier skew shift actuator mechanism arranged radially outward of the first carrier, a shaft coupled to the sun and a shaft indirectly coupled to the carrier.

Figure 7 is a schematic diagram of a carrier skew shift actuator mechanism having a shift fork.

Figure 8 is a schematic diagram of a carrier skew shift actuator mechanism having an axially translating housing member.

Figure 9 is a schematic diagram of a carrier skew shift actuator mechanism having a lever.

Figure 10 is a schematic diagram of a carrier skew shift actuator mechanism having an adjustment screw.

Figure 11 is a schematic diagram of a carrier skew shift actuator mechanism having a motor.

Figure 12 is a schematic diagram of a carrier skew shift actuator mechanism having a piston (hydraulic, pneumatic, electromagnetic).

Figure 13 is a schematic diagram of a hybrid powertrain having a continuously variable transmission coupled to a carrier skew shift actuator mechanism and coupled to multiple input/output power sources.

Figure 14 is a schematic diagram of a continuously variable transmission of the ball-type depicted in Figures 1-3 having a carrier skew shift actuator mechanism arranged radially inward of the first carrier, a shaft coupled to the sun and a shaft indirectly coupled to the carrier.

Figure 15 is a schematic diagram of a continuously variable transmission of the ball-type depicted in Figures 1-3 having yet another carrier skew shift actuator mechanism arranged radially inward of the first carrier, a shaft coupled to the sun and a shaft indirectly coupled to the carrier.

DETAILED DESCRIPTION

The preferred embodiments will now be described 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. Furthermore, embodiments include several novel features, no single one of which is solely responsible for its desirable attributes or which is essential to practicing the preferred embodiments described.

5 Provided herein are configurations of CVTs based on a ball type variators, also known as a CVP, for continuously variable planetary. Basic concepts of a ball type Continuously Variable Transmissions are described in United States Patent No. 8,469,856 and 8,870,711 incorporated herein by reference in their entirety. Such a CVT, adapted herein as described throughout this specification, comprises a number of balls (planets, spheres) 1, depending on the application, two
10 ring (disc) assemblies with a conical surface in contact with the balls, an input traction ring 2, an output traction ring 3, and an idler (sun) assembly 4 as shown on **FIG. 1**. The balls are mounted on tiltable axles 5, themselves held in a carrier (stator, cage) assembly having a first carrier member 6 operably coupled to a second carrier member 7. The first carrier member 6 rotates with respect to the second carrier member 7, and vice versa. In some embodiments, the first carrier member 6 is
15 substantially fixed from rotation while the second carrier member 7 is configured to rotate with respect to the first carrier member, and vice versa. In some embodiments, the first carrier member 6 is provided with a number of radial guide slots 8. The second carrier member 7 is provided with a number of radially offset guide slots 9, as illustrated in **FIG. 2**. The radial guide slots 8 and the radially offset guide slots 9 are adapted to guide the tiltable axles 5. The axles 5 are adjusted to
20 achieve a desired ratio of input speed to output speed during operation of the CVT. In some embodiments, adjustment of the axles 5 involves controlling the angular alignment of the first 6 and second 7 carrier members with respect to each other to impart a tilting of the axles 5 which thereby adjusts the speed ratio of the variator. Other types of ball CVTs also exist, but are slightly different.

 The working principle of such a CVP of **FIG. 1** is shown on **FIG. 3**. The CVP itself works
25 with a traction fluid. The fluid trapped in the contact between the ball and the conical rings acts as a solid at high pressure, transferring the power from the input ring, through the balls, to the output ring. By tilting the balls' axes, the ratio is changed between the input and output traction rings. When the axis is horizontal the ratio is one, illustrated in **FIG. 3**. When the axis is tilted, the distance between the ball axis and the contact points change, modifying the overall ratio. All the
30 balls' axes are tilted at the same time with a mechanism included in the carrier and/or idler.

 Embodiments 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 are adjusted to achieve a

desired ratio of input speed to output speed during operation. In some embodiments, adjustment of said axis of rotation involves changing the angular alignment of the planet axis in a first plane in order to achieve an angular adjustment of the planet axis in a second plane that is substantially perpendicular to the first plane, thereby adjusting the speed ratio of the variator. This angular misalignment in the first plane is referred to here as “skew”, “skew angle”, and/or “skew condition”. In some embodiments, a control system coordinates the use of a skew angle to generate steering angle forces between certain contacting components in the variator that will tilt the planet axis of rotation. The tilting of the planet axis of rotation adjusts the speed ratio of the variator.

For description purposes, 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. 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. For clarity and conciseness, at times similar components labeled similarly (for example, bearing 1011A and bearing 1011B) will be referred to collectively by a single label (for example, bearing 1011).

As used here, the terms “operationally connected,” “operationally coupled”, “operationally linked”, “operably connected”, “operably coupled”, “operably linked,” “operably coupleable” 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 take a variety of forms, which in certain instances will be readily apparent to a person of ordinary skill in the relevant technology.

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 force which would be available at the interfaces of the contacting components and is the ratio of the maximum available drive torque per contact force. 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 operate in both tractive and frictional applications. For example, in the embodiment where a CVT is used for a bicycle application, the CVT operates at times as a friction drive and at other times as a traction drive, depending on the torque and speed conditions present during operation.

As used here, the term infinitely variable transmission (IVT) is a type of continuously variable transmission (CVT) that can ratio to zero speed at one of the driving elements. An IVT comprises a CVT and all of the claims herein can pertain to both CVTs and IVTs that use a continuously variable planetary (CVP).

Referring now to **FIG. 4**, in some embodiments, a continuously variable transmission (CVT) 10 includes a CVP of the type described in FIGS. 1-3. The CVT 10 has a first carrier member 11 and a second carrier member 12 each configured to support a number of balls 22. The CVT 10 has a first traction ring assembly 13 and a second traction ring assembly 14 coupled to each ball 22. The CVT 10 has a sun assembly 15 coupled to each ball 22. The sun assembly 15 is positioned radially inward of each ball 22. The CVT 10 has a first rotatable shaft 16a coupled to the first carrier member 11. In some embodiments, the sun assembly 15 is rotatably supported on the first rotatable shaft 16a with a bearing, for example. The second carrier member 12 is rotatably supported on the first rotatable shaft 16a with a bearing, for example. The CVT 10 has a second rotatable shaft 17 coupled to the first traction ring assembly 13. The CVT 10 has a third rotatable shaft 18 coupled to the second traction ring assembly 14. The CVT 10 has a first axial thrust bearing 19 coupled to the first traction ring assembly 13 and a grounded member of the transmission, such as a housing (not shown). The CVT 10 has a second axial thrust bearing 20 coupled to the second traction ring assembly 14 and a grounded member of the transmission, such as a housing (not shown). The first rotatable shaft 16a is optionally configured to be rotatably supported with bearings between the second rotatable shaft 17 and the third rotatable shaft 18. In some embodiments, the CVT 10 is optionally configured with a fourth rotatable shaft 16b coupled to the first rotatable shaft 16a. The first rotatable shaft 16a, the second rotatable shaft 17, the third rotatable shaft 18, and the fourth rotatable shaft 16b are each configured to transmit/receive rotational power. In some embodiments, the first rotatable shaft 16a, the second rotatable shaft 17, the third rotatable shaft 18 and the fourth rotatable shaft 16b are optionally configured to couple to an input or output source of rotational power such as an engine, a motor (electric hydraulic, pneumatic), a generator, a flywheel, auxiliary power devices (fans, air conditioners, pumps), energy storage devices, upstream or downstream

gearing, among others. It should be appreciated, that additional gearing, chain drives, or countershafts are optionally configured to be used in the embodiments disclosed herein.

Still referring to **FIG. 4**, in some embodiments, the CVT 10 is provided with a carrier skew shift actuator mechanism 30. The carrier skew shift actuator mechanism 30 includes a driver shaft 31 adapted to rotate and to translate axially. In some embodiments, the driver shaft 31 is supported by roller or needle bearings, for example, that facilitate axial translation and rotation. The carrier skew shift actuator mechanism 30 includes a first helical gear 32 and a second helical gear 33 coupled to the driver shaft 31. The first helical gear 32 is coupled to the first carrier member 11. In some embodiments, the first helical gear 32 has helical teeth engaged with the first carrier member 11. The second helical gear 33 is coupled to the second carrier member 12. In some embodiments, the second helical gear 33 has helical teeth engaged with the second carrier member 12. The first helical gear 32 and the second helical gear 33 have helical teeth with different helix angles. In some embodiments, the first helical gear 32 and the second helical gear 33 have common pitch diameters.

During operation of the CVT 10, an adjustment to the relative rotation of the first carrier member 11 with respect to the second carrier member 12 corresponds to a change in the variator speed. The carrier skew shift actuator mechanism 30 facilitates the relative rotation of the first carrier member 11 with respect to the second carrier member 12. For example, an axial translation of the driver shaft 31 corresponds to an axial translation of the first helical gear 32 and the second helical gear 33. Since the first helical gear 32 and the second helical gear 33 have different helix angles, an axial translation of driver shaft 31 rotates the first carrier member 11 with respect to the second carrier member 12 as the first helical gear 32 and the second helical gear 33 move across gear interfaces of the first carrier member 11 and the second carrier member 12, respectively. It should be appreciated that the selection of the helical angle of the gear teeth on the first helical gear 32 and the second helical gear 33 is within a designer's choice to produce a desired phasing of the first carrier member 11 and the second carrier member 12 for a given axial translation of the driver shaft 31. In some embodiments, the first helical gear 32 is formed with straight gear teeth and the second helical gear 33 has angled gear teeth, or vice versa.

Turning now to **FIG. 5**, in some embodiments, a continuously variable transmission (CVT) 40 has a first carrier member 41 and a second carrier member 42 adapted to support a number of tiltable balls. For discussion purposes, only the differences between CVT 40 and CVT 10 will be described. In some embodiments, the CVT 40 includes a first traction ring assembly 43 and a second traction ring assembly 44, each in contact with the tiltable balls. The CVT 40 has a sun

assembly 45 in contact with the tiltable balls. The sun assembly 45 is arranged radially inward of the tiltable balls and the first traction ring assembly 43 and the second traction ring assembly 44. The CVT 40 includes a first rotatable shaft 46a coupled to the sun assembly 45. The CVT 40 has a second rotatable shaft 47 coupled to the second traction ring assembly 44. The CVT 40 has a third
5 rotatable shaft 48 coupled to the first traction ring assembly 43. In some embodiments, the CVT 40 is optionally configured with a fourth rotatable shaft 46b coupled to the first rotatable shaft 46a. The first rotatable shaft 46a, the second rotatable shaft 47, the third rotatable shaft 48, and the fourth rotatable shaft 46b are each configured to transmit/receive rotational power. In some embodiments, the first rotatable shaft 46a, the second rotatable shaft 47, the third rotatable shaft 48 and the fourth
10 rotatable shaft 46b are optionally configured to couple to an input or output source of rotational power such as an engine, a motor (electric hydraulic, pneumatic), a generator, a flywheel, auxiliary power devices (fans, air conditioners, pumps), energy storage devices, upstream or downstream gearing, among others. In some embodiments, the CVT 40 includes the carrier skew shift actuator mechanism 30 coupled to the first carrier member 41 and the second carrier member 42 to facilitate
15 an adjustment of the tiltable balls during operation of the CVT 40. For example, the first helical gear 32 is coupled to the first carrier member 41. The second helical gear 33 is coupled to the second carrier member 42. In all other aspects the carrier skew shift actuator mechanism 30 functions as described previously for Fig. 4.

Referring now to **FIG. 6**, in some embodiments, a continuously variable transmission (CVT)
20 50 includes a first carrier member 51 and a second carrier member 52 adapted to support a number of tiltable balls. For discussion purposes, only the differences between the CVT 50, the CVT 40, or CVT 10 will be described. In some embodiments, the CVT 50 includes the carrier skew shift actuator mechanism 30. The first helical gear 32 is coupled to the first carrier member 51. The second helical gear 33 is coupled to the second carrier member 52. In some embodiments, the CVT
25 50 includes a first power transfer gear 53 coupled to the driver shaft 31. The first power transfer gear 53 is coupled to a second power transfer gear 54. The second power transfer gear 54 is coupled to a fifth rotatable shaft 55. The fifth rotatable shaft 55 is adapted to transmit/receive rotational power. In some embodiments, the fifth rotatable shaft 55 is optionally configured to couple to an input or output source of rotational power such as an engine, a motor (electric hydraulic, pneumatic),
30 a generator, a flywheel, auxiliary power devices (fans, air conditioners, pumps), energy storage devices, upstream or downstream gearing, among others. During operation of the CVT 50, the carrier skew shift actuator mechanism 30 is adapted to facilitate an adjustment of the tiltable balls.

In all other aspects the carrier skew shift actuator mechanism 30 functions as described previously for Fig. 4.

Referring now to **FIGS. 7-12**, various optional embodiments of mechanisms and assemblies for facilitating an axial translation of the driver shaft 31 will now be described.

5 Referring specifically to **FIG. 7**, in some embodiments, the driver shaft 31 with the first helical gear 32 and the second helical gear 33 coupled thereto, is coupled to a collar 60. The collar 60 engages a shift fork 61. The collar 60 is configured to rotate with respect to the shift fork 61. The shift fork 61 is optionally configured to be manually accessible by a user and configured mechanically through linkages, gears, screws, cams, or automated by use of a motor (electric, servo,
10 stepper, hydraulic, pneumatic), a piston (hydraulic, pneumatic, electromagnetic), or other device, and configured to be moved in the axial direction.

Referring specifically to **FIG. 8**, in some embodiments, the driver shaft 31 is coupled to a coupling nut 65. The coupling nut 65 is configured to rotate with the driver shaft 31 with the first helical gear 32 and the second helical gear 33 coupled thereto. The coupling nut 65 is supported in a
15 housing member 66 by a bearing 67. The housing member 66 is coupled to ground with an anti-rotation device (for example a pin or spline roller) 68. The housing member 66 is adapted to translate axially with substantially no rotation.

Referring specifically to **FIG. 9**, in some embodiments, the driver shaft 31 is coupled to a coupling nut 65. The coupling nut 65 is configured to rotate with the driver shaft 31 with the first
20 helical gear 32 and the second helical gear 33 coupled thereto. The coupling nut 65 is supported in a housing member 66 by a bearing 67. The housing member 66 is coupled to ground with an anti-rotation device (for example a pin or spline roller) 68. The housing member 66 is optionally configured to couple to a lever 69 with a linkage 70. The lever 69 is configured to have a pivot on one end. In some embodiments, the linkage 70 is a solid member configured to have a pivot on each
25 end to thereby transfer axial movement corresponding to the rotational movement of the lever 69. A rotational displacement of the lever 69 about the pivot and the corresponding axial displacement of the linkage 70 corresponds to an axial translation of the housing member 66.

Referring specifically to **FIG. 10**, in some embodiments, the driver shaft 31 is coupled to a coupling nut 65. The coupling nut 65 is configured to rotate with the driver shaft 31 with the first
30 helical gear 32 and the second helical gear 33 coupled thereto. The coupling nut 65 is supported in a housing member 66 by a bearing 67. The housing member 66 is coupled to ground with an anti-rotation device (for example a pin or spline roller) 68. The housing member 66 is provided with a

screw thread 75 adapted to receive adjustment mating screw thread 76. Since the housing member 66 is constrained from rotation by the anti-rotation device 68, a rotation of the screw thread 76 corresponds to an axial translation of the housing member 66.

Referring now to **FIG. 11**, in some embodiments, the driver shaft 31 is coupled to a coupling nut 65. The coupling nut 65 is configured to rotate with the driver shaft 31 with the first helical gear 32 and the second helical gear 33 coupled thereto. The coupling nut 65 is supported in a housing member 66 by a bearing 67. The housing member 66 is coupled to ground with an anti-rotation device (for example a pin or spline roller) 68. The housing member 66 is provided with a screw thread 75 adapted to receive adjustment mating screw thread 76. The screw thread 76 is coupled to a motor (electric, servo, stepper, hydraulic or pneumatic) 77. The motor 77 is optionally configured to be actuated by the control system of the CVT. The motor 77 is typically configured to provide a controlled rotation based on a control system commanded input and optional sensor feedback.

Referring now to **FIG. 12**, in some embodiments, the driver shaft 31 is coupled to a coupling nut 65. The coupling nut 65 is configured to rotate with the driver shaft 31 with the first helical gear 32 and the second helical gear 33 coupled thereto. The coupling nut 65 is supported in a housing member 66 by a bearing 67. The housing member 66 is coupled to ground with an anti-rotation device (for example a pin or spline roller) 68. The housing member 66 is coupled to a hydraulic piston 80 housed in a hydraulic manifold 81. The hydraulic manifold 81 is optionally configured to be in fluid communication with a lubrication and hydraulic control system equipped on the CVT. The hydraulic manifold 81 has a first pressurized chamber on one side of the hydraulic piston 80 and a second pressurized chamber on the opposite side of the hydraulic piston 80. During operation of the CVT, a differential pressure between the first pressurized chamber and the second pressurized chamber corresponds to an axial movement of the hydraulic piston 80. In some embodiments, the piston is optionally configured to be controlled via the hydraulic control system as a piston displacement, and/or as a piston force reacting to the resultant axial force on driver shaft 31 from the carrier torque being transferred through the first helical gear 32 and the second helical gear 33. It should be apparent to one skilled in the art that a pneumatic piston or electromagnetic device (solenoid, linear motor), or other could also be used in place of the hydraulic piston afore mentioned.

Turning now to **FIG. 13**, a hybrid powertrain 90 is configured with the CVT 40 coupled to the carrier skew shift actuator mechanism 30. The hybrid powertrain 90 includes an internal combustion engine (ICE) 91, a first motor-generator 92, a second motor-generator 93, a third motor-generator 94, and a fourth motor-generator 95. Each motor-generator is configured to be in

electrical communication with a battery system (not shown). The hybrid powertrain 90 includes a first brake 96, a second brake 97, a third brake 98, and a fourth brake 99. The hybrid powertrain 90 includes a first planetary gear set 100 having a first sun gear, a second sun gear, a first planetary carrier operably coupled to a first planet gear and a second planet gear. The first planet gear is engaged to the first sun gear. The second planet gear is engaged to the second sun gear. The hybrid powertrain 90 includes a second planetary set 101 having a third sun gear, a fourth sun gear, a second planetary carrier a operably coupled to a third planet gear and a fourth planet gear. The third planet gear is engaged to the third sun gear. The fourth planet gear is engaged to the fourth sun gear. In some embodiments, the ICE 91 is coupled to a first rotatable shaft 102. A first clutch 103 and a second clutch 104 are coupled coaxially with the first rotatable shaft 102. The first clutch 103 is operably coupled to the first motor-generator 92. The first motor-generator 92 and the first brake 96 are coupled to the first sun gear of the first planetary gear set 100. The second motor-generator 93 and the second brake 97 are coupled to the first planetary carrier of the first planetary gear set 100.

In some embodiments, the second clutch 104 is coupled to the first planetary carrier of the first planetary gear set 100. The sun assembly 45 is coupled to the first planetary carrier. The second traction ring assembly 44 is coupled to the second sun gear of the first planetary gear set 100. In some embodiments, a third clutch 105 is coupled to the driver shaft 31. The third clutch 105 is positioned between the first helical gear 32 and the second helical gear 33. The first power transfer gear 53 is operably coupled to the third motor-generator 94 and the third brake 98. In some embodiments, the first traction ring assembly 43 is coupled to the third sun gear of the second planetary gear set 101. The fourth motor generator 95 and the fourth brake 99 are operably coupled to the fourth sun gear of the second planetary gear set 101.

In some embodiments, the hybrid powertrain 90 includes a fourth clutch 106 and a fifth clutch 107 arranged coaxially with the first rotatable shaft 102. The fourth clutch 106 is operably coupled to the second planetary carrier of the second planetary gear set 101. The fifth clutch 107 is operably coupled to the fourth sun gear of the second planetary gear set 101. The fourth clutch 106 and fifth clutch 107 are coupled coaxially to a second rotatable shaft 108. The second rotatable shaft 108 is adapted to transmit an output power from the hybrid powertrain 90. In some embodiments, the hybrid powertrain 90 includes a third rotatable shaft 109 adapted to transmit an output power from the hybrid powertrain 90. The third rotatable shaft 109 is coupled to the fourth motor-generator 95.

During operation of the hybrid powertrain 90, the carrier skew shift actuator mechanism 30 is controlled by a supervisory control system (not shown) to adjust the CVT 50 and manage the power flow through the powertrain for optimal charging/discharging of the battery system (not shown) and performance of the vehicle equipped with the hybrid powertrain 90. It should be apparent to one skilled in the art that the power devices, ICEs, motors, generators, brakes, clutches and power outputs can be utilized as needed for the application, and not all of the devices need to be present, but are application dependent.

Passing now to **FIG. 14**, in some embodiments a continuously variable transmission (CVT) 150 includes a first carrier member 151 and a second carrier member 152 configured to support a number of tiltable balls. The CVT 150 is optionally configured to have the carrier skew shift actuator mechanism 30 arranged radially inward of a first traction ring assembly 153 and a second traction ring assembly 154. The first traction ring assembly 153 and the second traction ring assembly 154 are in contact with each tiltable ball. The first carrier member 151 is coupled to the first helical gear 32. The second carrier member 152 is coupled to the second helical gear 33. In some embodiments, the second traction ring assembly 154 is a grounded member. The CVT 150 includes a first rotatable shaft 155a coupled to the first carrier member 151. The CVT 150 includes a second rotatable shaft 156 coupled to the first traction ring assembly 153. In some embodiments, the CVT 150 is optionally configured with a third rotatable shaft 155b coupled to the first rotatable shaft 155a. The CVT 150 includes a first power transfer gear 157 coupled to the driver shaft 31. The first power transfer gear 157 is drivingly engaged with a second power transfer gear 158 coupled to a fourth rotatable shaft 159. The first rotatable shaft 155a, the second rotatable shaft 156, the third rotatable shaft 155b and the fourth rotatable shaft 158 are each configured to transmit/receive rotational power.

In some embodiments, the first rotatable shaft 155a, the second rotatable shaft 156, the third rotatable shaft 155b and the fourth rotatable shaft 158 are optionally configured to couple to an input or output source of rotational power such as an engine, a motor (electric hydraulic, pneumatic), a generator, a flywheel, auxiliary power devices (fans, air conditioners, pumps), energy storage devices, upstream or downstream gearing, among others. During operation of the CVT 150, an axial translation of the driver shaft 31 corresponds to a relative rotation between the first carrier member 151 and the second carrier member 152 to facilitate an adjustment of the tiltable balls during operation of the CVT 150.

Turning now to **FIG. 15**, in some embodiments, a continuously variable transmission (CVT) 160 includes a first carrier member 161 and a second carrier member 162 configured to support a number of tiltable balls. The CVT 160 includes a first traction ring assembly 163 and a second traction ring assembly 164, each in contact with the tiltable balls. The CVT 160 includes a first rotatable shaft 165a drivingly engaged to the first carrier member 161. The CVT 160 includes a second rotatable shaft 166 coupled to the first traction ring assembly 163. In some embodiments, the CVT 160 is optionally configured with a third rotatable shaft 165b coupled to the first rotatable shaft 165a. The CVT 160 includes an internal gear 171 coupled to the second carrier 162. The carrier skew shift actuator mechanism 170 includes a first idler gear 172 coupled to the internal gear 171. The first idler gear 172 is coupled to a first helical gear 173. The first helical gear 173 is coupled to the driver shaft 176. The driver shaft 176 is coupled to a second helical gear 174. The second helical gear 174 is coupled to a third helical gear 175 and helical gear 175 is coupled to the first rotatable shaft 165a. In some embodiments, the CVT 160 includes a first power transfer gear 169 coupled to the driver shaft 176. The first power transfer gear 169 is drivingly engaged with a second power transfer gear 168 coupled to a fourth rotatable shaft 167. The first rotatable shaft 165a, the second rotatable shaft 166, the third rotatable shaft 165b and the fourth rotatable shaft 167 are each configured to transmit/receive rotational power.

In some embodiments, the first rotatable shaft 165a, the second rotatable shaft 166, the third rotatable shaft 165b and the fourth rotatable shaft 167 are optionally configured to couple to an input or output source of rotational power such as an engine, a motor (electric hydraulic, pneumatic), a generator, a flywheel, auxiliary power devices (fans, air conditioners, pumps), energy storage devices, upstream or downstream gearing, among others. The driver shaft 176 is adapted to rotate and translate axially. Conversely, the idler gear 172 can be adapted to rotate and translate axially. During operation of the CVT 160, an axial translation of the driver shaft 176, or the idler gear 172, corresponds to a relative rotation between the first carrier member 161 and the second carrier member 162 to facilitate an adjustment of the tiltable balls during operation of the CVT 160.

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 preferred embodiments 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 any one claim makes a specified dimension, or range of thereof, a feature of the claim.

While preferred embodiments of the present embodiments have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the preferred embodiments. It should be understood that various alternatives to the embodiments described herein may be employed in practicing the preferred embodiments. It is intended that the following claims define the scope of the embodiments and that methods and structures within the scope of these claims and their equivalents be covered thereby.

It should be noted that where an ICE and a motor-generators are described, the device are optionally configured to be any source that transmits/receives rotational power, such as an internal combustion engine (diesel, gasoline, natural gas, hydrogen), motor or generators/alternators, electric machines, hydromotors and pumps, pneumatic motors and pumps, kinetic devices or other rotational power source. Along the same lines, the battery is optionally configured to not only be a high voltage pack such as lithium ion or lead-acid batteries, but also ultracapacitors, a fuel cell system, other pneumatic/hydraulic systems such as accumulators, kinetic devices, or other forms of energy storage systems. The powertrain architectures depicted in the figures and described in text can be extended to create a hybrid-mechanical CVT architecture as well for hydraulic or pneumatic hybrid systems. It should be appreciated that the hybrid architectures disclosed herein optionally include additional clutches, brakes, gearing, pulleys, shafting and couplings to meet the needs of the hybrid CVP application.

CLAIMS

WHAT IS CLAIMED IS:

1. A carrier skew shift actuator mechanism for a continuously variable transmission (CVT) having a plurality of tiltable balls supported by a first carrier member and a second carrier member, each ball in contact with a first traction ring assembly and a second traction ring assembly, the carrier skew shift actuator mechanism comprising:
 - a first helical gear comprising a first set of helical teeth, coupled to the first carrier member;
 - a second helical gear comprising a second set of helical teeth, coupled to the second carrier member; and
 - a driver shaft coupled to the first helical gear and the second helical gear, wherein the driver shaft is rotatable and adapted to translate axially.
2. The carrier skew shift actuator mechanism of Claim 1, wherein the first set of helical teeth are at a different angle than the second set of helical teeth.
3. The carrier skew shift actuator mechanism of Claim 1, further comprising a shift fork operably coupled to the driver shaft.
4. The carrier skew shift actuator mechanism of Claim 1, further comprising a lever operably coupled to the driver shaft.
5. The carrier skew shift actuator mechanism of Claim 1, further comprising an adjustment screw operably coupled to the driver shaft.
6. The carrier skew shift actuator mechanism of Claim 1, further comprising a motor operably coupled to the driver shaft.
7. The carrier skew shift actuator mechanism of Claim 1, further comprising a piston operably coupled to the driver shaft.
8. The carrier skew shift actuator mechanism of Claim 7, further comprising a hydraulic manifold coupled to the piston.
9. The carrier skew shift actuator mechanism of Claim 1, wherein an axial translation of the driver shaft corresponds to a relative rotation of the first carrier member with respect to the second carrier member.
10. A continuously variable transmission comprising:
 - a plurality of tiltable balls arrayed radially about a longitudinal axis of the transmission;

a first carrier member having a first plurality of guide slots, the tiltable balls operably coupled to the first plurality of guide slots;

a second carrier member having a second plurality of guide slots, the tiltable balls operably coupled to the second plurality of guide slots, wherein the second plurality of guide slots are radially offset from the first plurality of guide slots;

a first traction ring assembly in contact with each tiltable ball;

a second traction ring assembly in contact with each tiltable ball; and

a carrier skew shift actuator mechanism comprising:

a first helical gear coupled to the first carrier member;

a second helical gear coupled to the second carrier member; and

a driver shaft coupled to the first helical gear and the second helical gear.

11. The continuously variable transmission of Claim 10, wherein an axial translation of the driver shaft corresponds to a relative rotation of the first carrier member with respect to the second carrier member.

12. The continuously variable transmission of Claim 11, wherein the carrier skew shift actuator mechanism is arranged radially outward of the first carrier member and the second carrier member.

13. The continuously variable transmission of Claim 11, wherein the carrier skew shift actuator mechanism is arranged radially inward of the first traction ring assembly and the second traction ring assembly.

14. The continuously variable transmission of Claim 11, further comprising a sun assembly in contact with each tiltable ball, the sun assembly located radially inward of the first traction ring assembly and the second traction ring assembly.

15. The continuously variable transmission of Claim 14, further comprising a first rotatable shaft coupled to the sun assembly.

16. A hybrid powertrain comprising:

an internal combustion engine (ICE);

a first motor-generator;

a second motor-generator;

a third motor-generator;

a fourth motor-generator;

a first planetary gear set having a first sun gear, a first planetary carrier, a second sun gear, a first planet gear, and a second planet gear;

a second planetary gear set having a third sun gear, a second planetary carrier, a fourth sun gear, a third planet gear, and a fourth planet gear;

wherein the first motor-generator is coupled to the first sun gear,

wherein the second motor-generator is coupled to the first planet carrier,

wherein the fourth motor-generator is coupled to the fourth sun gear,

a continuously variable transmission comprising:

a plurality of tiltable balls arrayed radially about a longitudinal axis of the transmission;

a first carrier member having a first plurality of guide slots, the tiltable balls operably coupled to the first plurality of guide slots;

a second carrier member having a second plurality of guide slots, the tiltable balls operably coupled to the second plurality of guide slots, wherein the second plurality of guide slots are radially offset from the first plurality of guide slots;

a first traction ring assembly in contact with each tiltable ball, the first traction ring assembly coupled to the third sun gear;

a second traction ring assembly in contact with each tiltable ball, the second traction ring assembly coupled to the second sun gear; and

a carrier skew shift actuator mechanism comprising:

a first helical gear coupled to the first carrier member;

a second helical gear coupled to the second carrier member; and

a driver shaft coupled to the first helical gear and the second helical gear, the driver shaft operably coupled to the third motor-generator.

17. The hybrid powertrain of Claim 16, further comprising:

a first brake operably coupled to the first sun gear;

a second brake operably coupled to the first planet carrier;

a third brake operably coupled to the driver shaft; and

a fourth brake operably coupled to the fourth sun gear.

18. The hybrid powertrain of Claim 17, further comprising:

a first clutch operably coupled to the first sun gear;

a second clutch operably coupled to the first clutch, the second clutch operably coupled to the first planetary carrier;

a third clutch coupled to the driver shaft, the third clutch positioned between the first helical gear and the second helical gear;

5 a fourth clutch coupled to the second planetary carrier; and

a fifth clutch coupled to the fourth clutch, the fifth clutch coupled to the fourth sun gear,

wherein the first planetary carrier is coupled to the sun assembly and the second planetary carrier.

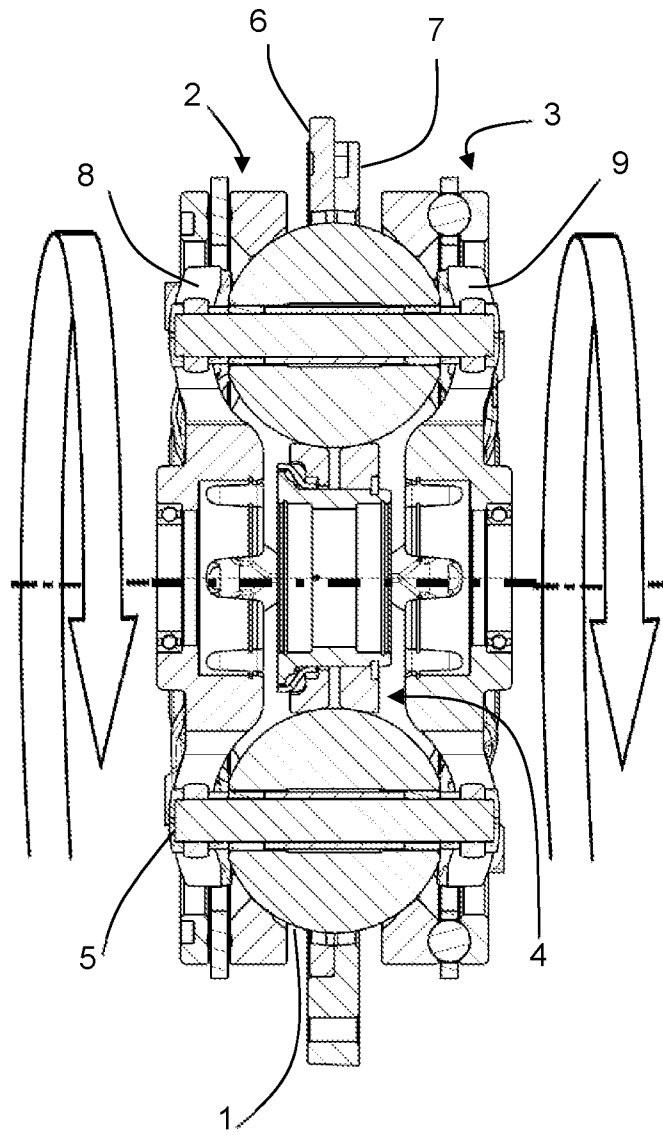


Figure 1

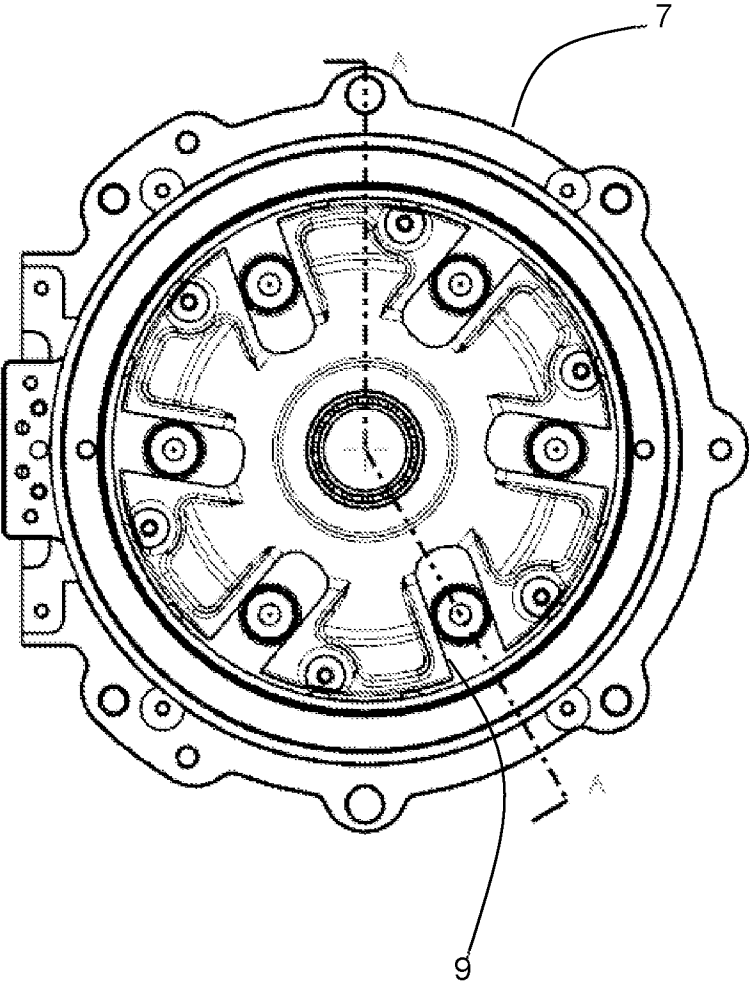


Figure 2

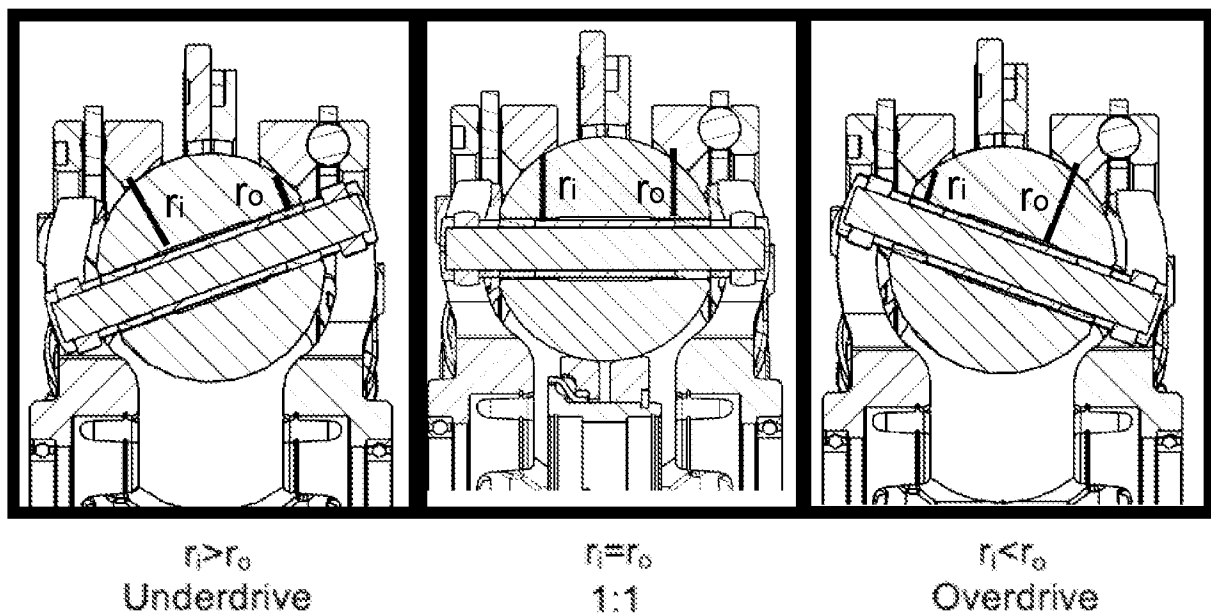


Figure 3

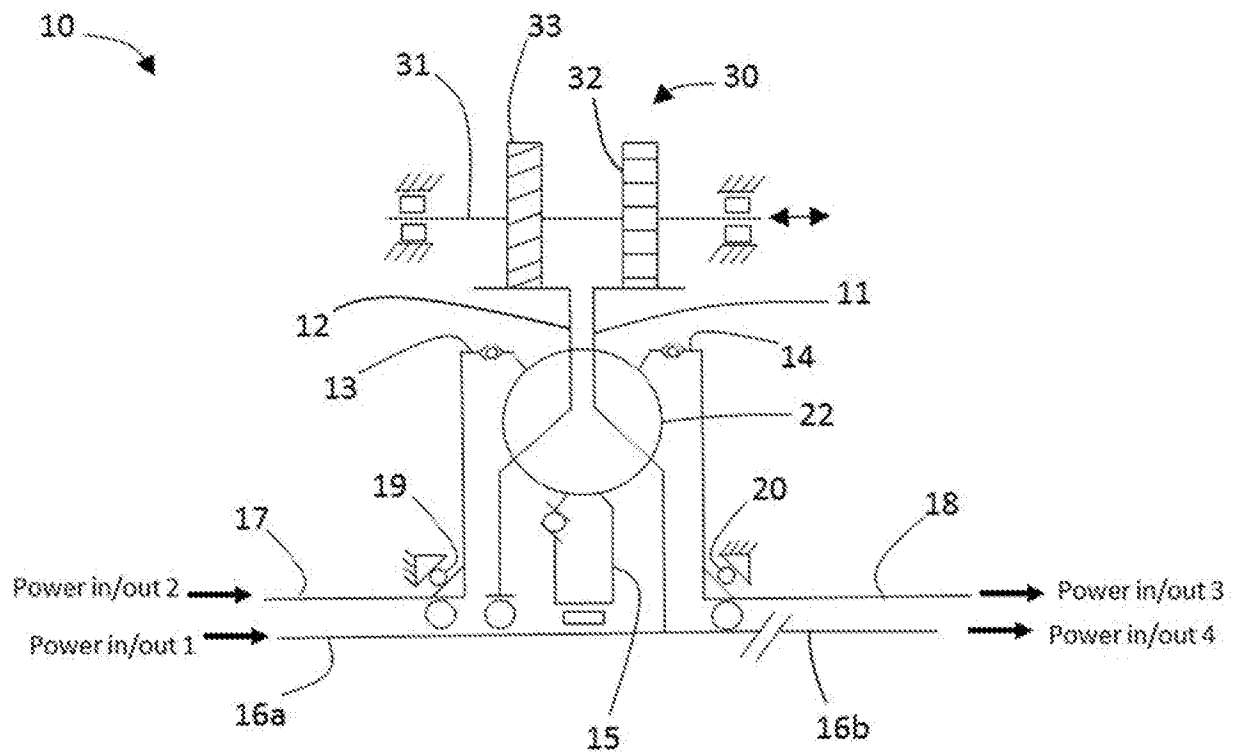


Figure 4

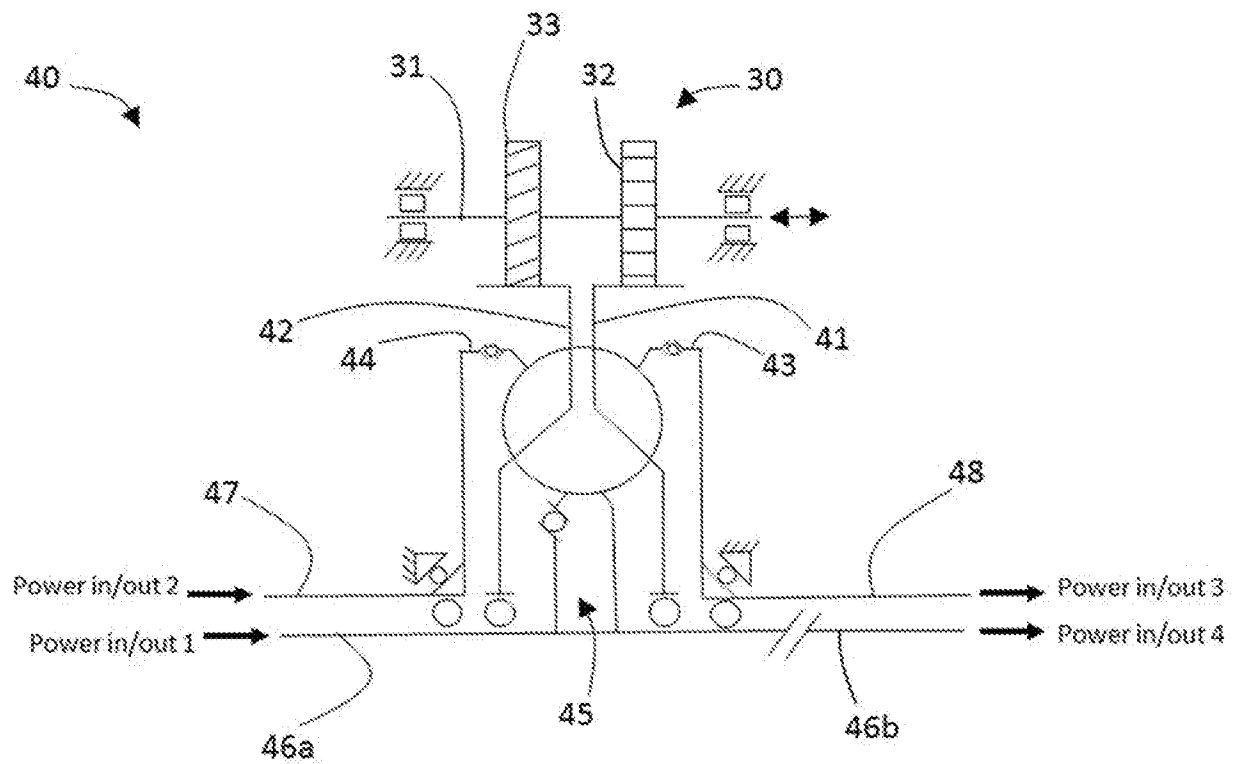


Figure 5

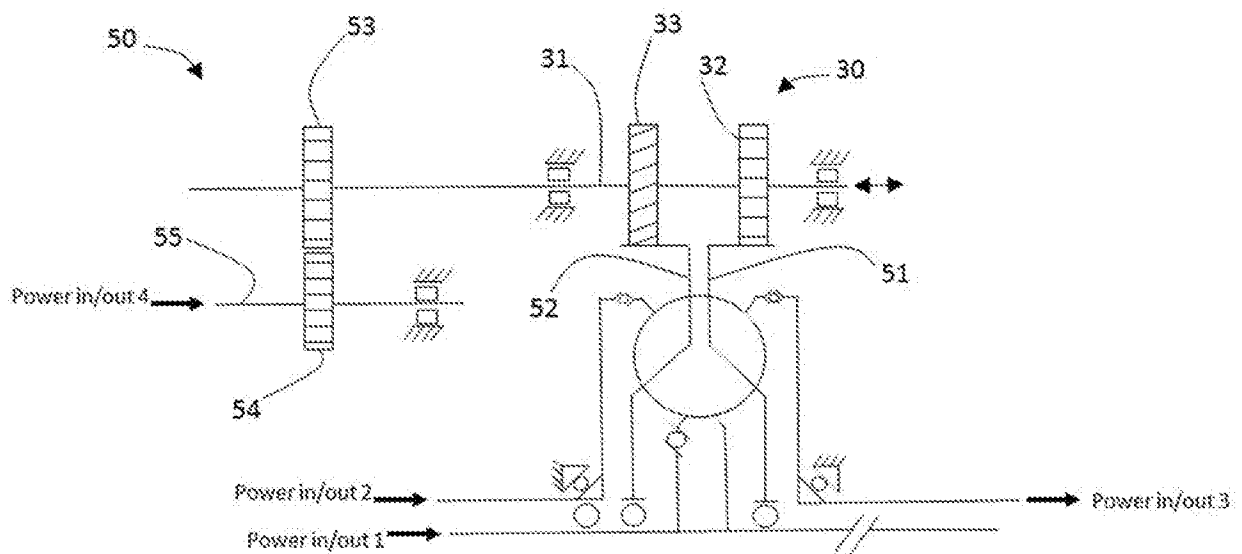


Figure 6

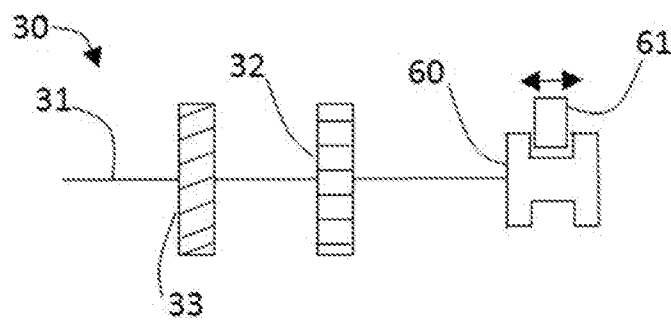


Figure 7

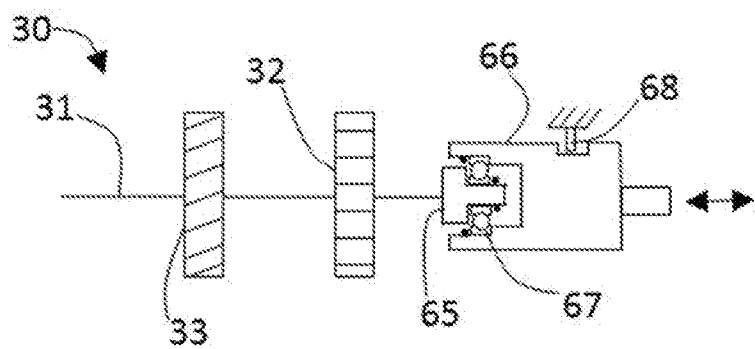


Figure 8

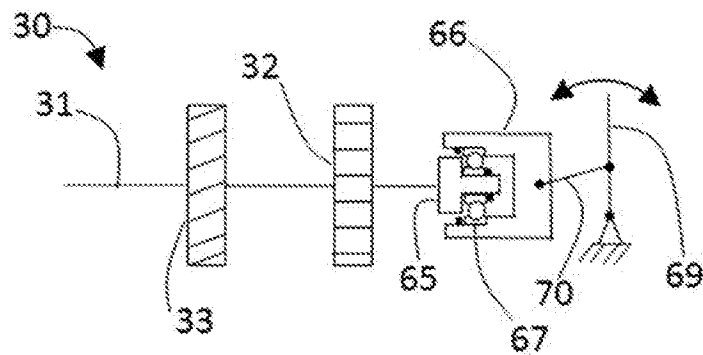


Figure 9

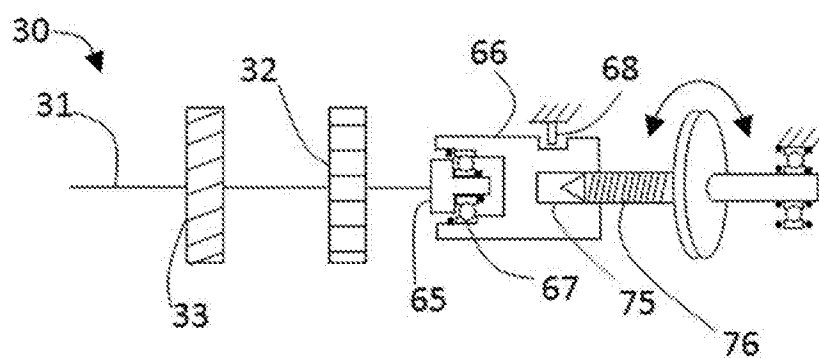


Figure 10

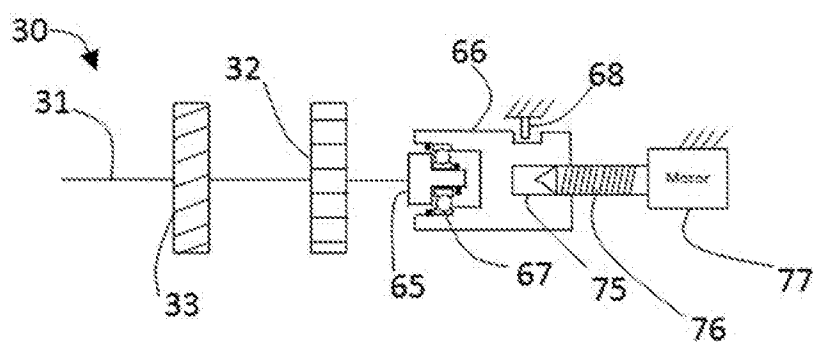


Figure 11

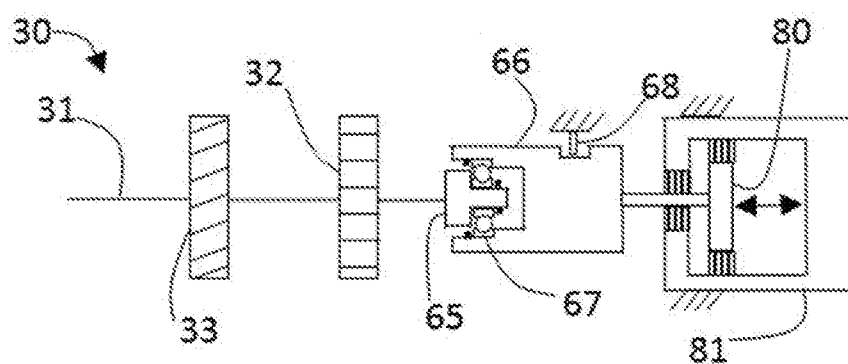


Figure 12

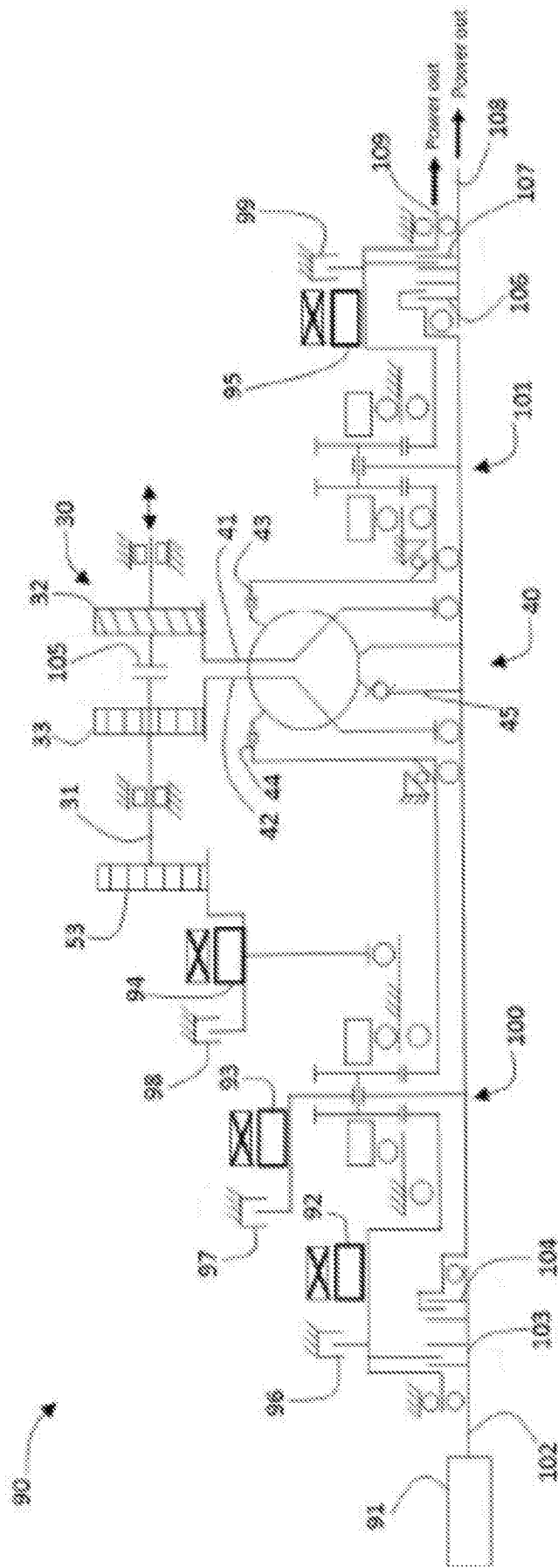


Figure 13

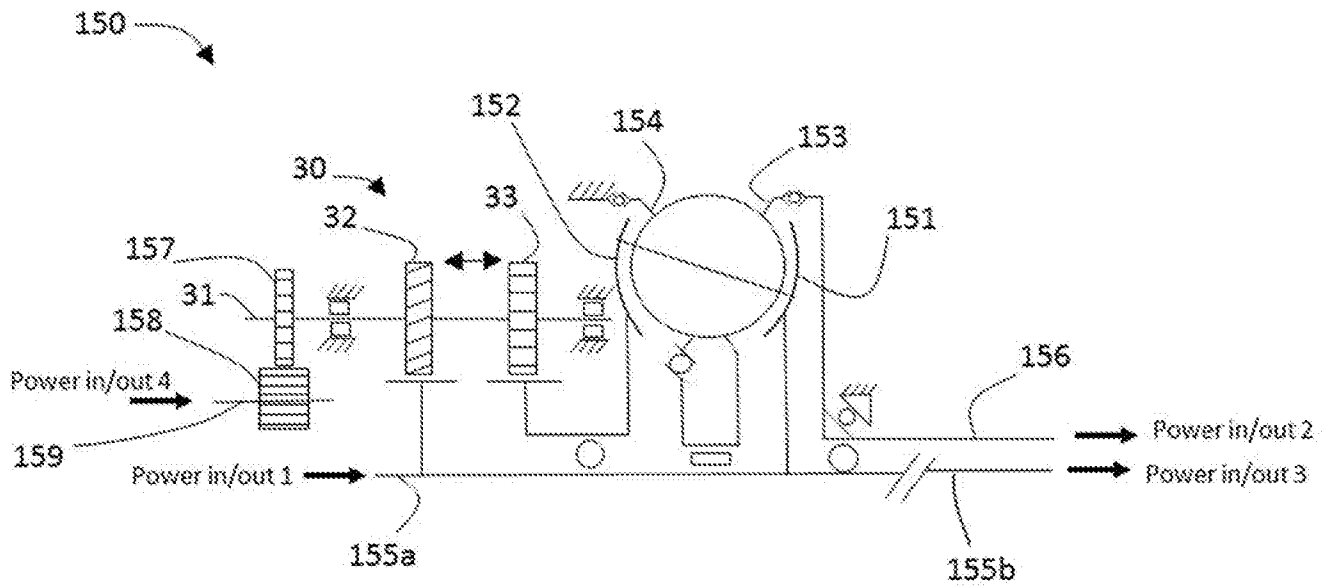


Figure 14

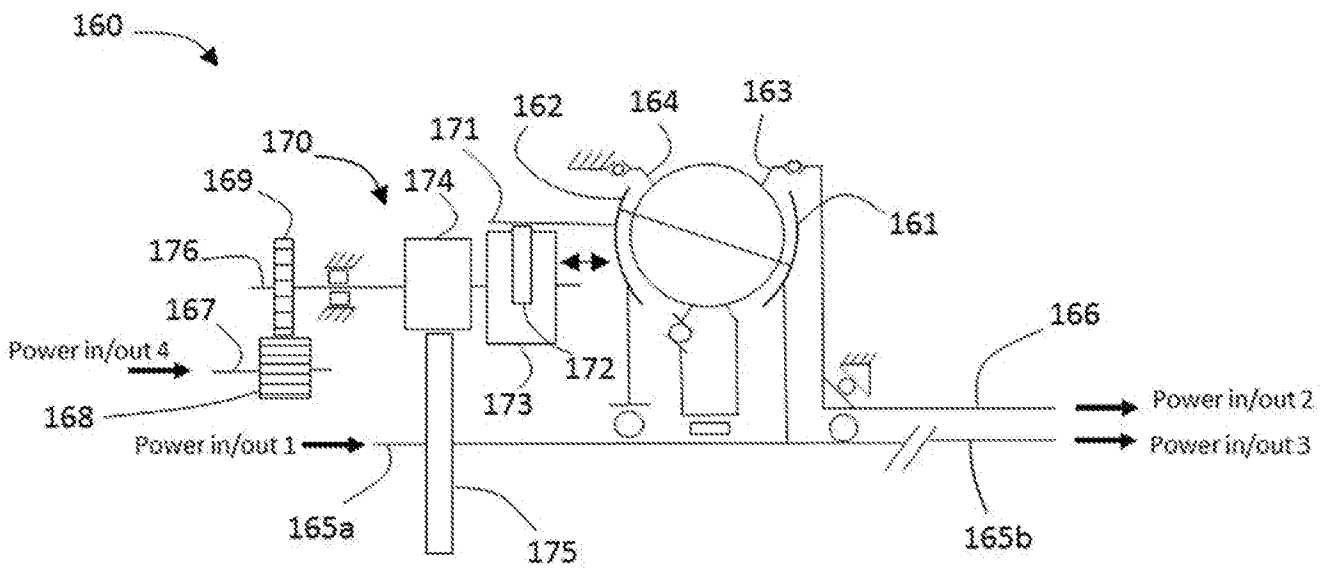


Figure 15

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/019944

A. CLASSIFICATION OF SUBJECT MATTER

INV. F16H63/06 F16H15/28
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F16H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/044778 A1 (FALLBROOK TECHNOLOGIES INC [US]; THOMASSY FERNAND A [US]; LOHR CHARLES) 22 April 2010 (2010-04-22)	1-8,10, 12-18
A	paragraphs [0001], [0154]; figures 4,51	9,11
A	US 2014/274551 A1 (YOUNGGREN BRUCE H [US] ET AL) 18 September 2014 (2014-09-18)	1
A	paragraphs [0069] - [0070]	3
A	JP 2015 232402 A (FALLBROOK INTELLECTUAL PROPERTY CO LLC) 24 December 2015 (2015-12-24)	
	figure 4	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

27 June 2017

Date of mailing of the international search report

06/07/2017

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/019944

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2010044778	A1	22-04-2010	CA 2740194 A1 22-04-2010
		CA 2924145 A1 22-04-2010	
		CN 102227577 A 26-10-2011	
		DK 2342479 T3 26-08-2013	
		DK 2620672 T3 24-08-2015	
		EP 2342479 A1 13-07-2011	
		EP 2620672 A1 31-07-2013	
		ES 2423934 T3 25-09-2013	
		ES 2545662 T3 14-09-2015	
		JP 5335092 B2 06-11-2013	
		JP 2012506001 A 08-03-2012	
		KR 20110079884 A 11-07-2011	
		RU 2011113409 A 27-11-2012	
		WO 2010044778 A1 22-04-2010	
US 2014274551	A1	18-09-2014	CA 2906343 A1 25-09-2014
		CN 105121904 A 02-12-2015	
		EP 2971857 A1 20-01-2016	
		US 2014274551 A1 18-09-2014	
		WO 2014150012 A1 25-09-2014	
JP 2015232402	A	24-12-2015	BR 112012022240 A2 25-10-2016
		CA 2791307 A1 09-09-2011	
		CN 102869900 A 09-01-2013	
		CN 106246836 A 21-12-2016	
		EP 2542800 A1 09-01-2013	
		EP 3021004 A1 18-05-2016	
		JP 5819863 B2 24-11-2015	
		JP 2013521452 A 10-06-2013	
		JP 2015232402 A 24-12-2015	
		KR 20130045852 A 06-05-2013	
		RU 2012140712 A 10-04-2014	
		TW 201144133 A 16-12-2011	
		TW 201634344 A 01-10-2016	
		TW 201708039 A 01-03-2017	
		US 2011218072 A1 08-09-2011	
		US 2013331218 A1 12-12-2013	
		US 2014248988 A1 04-09-2014	
		US 2016281825 A1 29-09-2016	
		WO 2011109444 A1 09-09-2011	