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(54) Title: POWERTRAINS HAVING A BALL-TYPE CONTINUOUSLY VARIABLE TRANSMISSION AND A RAVIGNEAUX PLANETARY GEAR SET

(57) Abstract: Provided herein are is a powertrain including: an engine; a continuously variable planetary transmission (CVP) having a plurality of balls, each ball provided with a tiltable axis of rotation, each ball in contact with a first traction ring assembly and a second traction ring assembly, and each ball operably coupled to a carrier; and a ravigneaux gear set having a common ring gear, a ravigneaux planet carrier supporting a first set of planet gears coupled to the common ring gear and a second set of planet gears coupled to the common ring gear, a first ravigneaux sun gear coupled to the first set of the planet gears, a second ravigneaux sun gear coupled to the second set of the planet gears, wherein the engine is operably coupled to the first traction ring assembly and the second traction ring assembly is coupled to the first ravigneaux sun gear.

POWERTRAINS HAVING A BALL-TYPE CONTINUOUSLY VARIABLE TRANSMISSION AND A RAVIGNEAUX PLANETARY GEAR SET

RELATED APPLICATION

The present application claims priority to U.S. Provisional patent application No. 62/545,146, filed on August 14, 2017, which is incorporated herein by reference in its entirety.

BACKGROUND

Hybrid vehicles are enjoying increased popularity and acceptance due in large part to the cost of fuel and greenhouse carbon emission government regulations for internal combustion engine vehicles. Such hybrid vehicles include both an internal combustion engine as well as an electric motor to propel the vehicle. 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 to operate at its most advantageous rotational speed.

In current designs for both consuming as well as storing electrical energy, the rotary shaft from a combination electric motor/generator is coupled by a gear train or planetary gear set to the main shaft of an internal combustion engine. As such, the rotary shaft for the electric motor/generator unit rotates in unison with the internal combustion engine main shaft at the fixed ratio of the hybrid vehicle design.

These fixed ratio designs have many disadvantages, for example, the electric motor/generator unit achieves its most efficient operation, both in the sense of generating electricity and also providing additional power to the main shaft of the internal combustion engine, only within a relatively narrow range of revolutions per minute of the motor/generator unit. However, since the previously known hybrid vehicles utilized a fixed speed ratio between the motor/generator unit and the internal combustion engine main shaft, the motor/generator unit oftentimes operates outside its optimal speed range. As such, the overall hybrid vehicle operates at less than optimal efficiency. Therefore, there is a need for powertrain configurations that improve the efficiency of hybrid vehicles.

Regular series-parallel hybrid electric powertrains (powersplit eCVT) are two-motor HEV propulsion systems mated with a planetary gear, and most mild or full parallel hybrid systems are single motor systems with a gearbox or continuously variable transmission coupled with an electric machine. Coupling a ball-type continuously variable planetary (CVP), such as a VariGlide®, with one electric machine enables the creation of a parallel HEV architecture with the CVP functioning as a continuously variable transmission, and the motor providing the functionality of electric assist, starter motor capability, launch assist and regenerative braking. Embodiments disclosed herein, coupled with a hybrid supervisory controller that chooses the path of highest efficiency from engine to wheel, provides a means to optimize the operation of the engine and motor/generator, thereby providing a hybrid powertrain that will operate at the best potential overall efficiency point in any mode and also provide torque variability, thereby leading to the best combination of powertrain performance and fuel efficiency that will exceed current industry standards especially in the mild-hybrid and parallel hybrid light vehicle segments.

SUMMARY

Provided herein is a powertrain including: an engine; a continuously variable planetary transmission (CVP) having a plurality of balls, each ball provided with a tiltable axis of rotation, each ball in contact with a first traction ring assembly and a second traction ring assembly, and each ball operably coupled to a carrier; and a ravigneaux gear set having a common ring gear, a ravigneaux planet carrier supporting a first set of planet gears coupled to the common ring gear and a second set of planet gears coupled to the common ring gear, a first ravigneaux sun gear coupled to the first set of the planet gears, a second ravigneaux sun gear coupled to the second set of the planet gears, wherein the engine is operably coupled to the first traction ring assembly and the second traction ring assembly is coupled to the first ravigneaux sun gear.

In some embodiments, the common ring gear is adapted to transmit power from the powertrain.

In some embodiments, the powertrain includes a first mode clutch configured to selectively couple the second ravigneaux sun gear to ground.

In some embodiments, the powertrain includes a second mode clutch configured to selectively couple the first ravigneaux sun gear to the second ravigneaux sun gear.

In some embodiments, the powertrain includes a reverse clutch configured to selectively couple the ravigneaux planet carrier to ground.

In some embodiments, the powertrain includes a motor/generator operably coupled to the first ravigneaux sun gear.

In some embodiments, the powertrain includes a motor/generator operably coupled to the second ravigneaux sun gear.

In some embodiments, the powertrain includes a motor/generator operably coupled to the planet ravigneaux carrier.

Provided herein is a powertrain including: an engine; a continuously variable planetary transmission (CVP) having a plurality of balls, each ball provided with a tiltable axis of rotation, each ball in contact with a first traction ring assembly and a second traction ring assembly, and each ball operably coupled to a carrier; a planetary gear set having a first ring gear operably coupled to the first traction ring assembly, a first planet carrier operably to the engine, and a first sun gear operably coupled to the second traction ring assembly; and a ravigneaux gear set having a common ring gear, a ravigneaux planet carrier supporting a first set of planet gears coupled to the common ring gear and a second set of planet gears coupled to the common ring gear, a first ravigneaux sun gear coupled to the first set of the planet gears, a second ravigneaux sun gear coupled to the second set of the planet gears, wherein the first sun gear is operably coupled to the first ravigneaux sun gear.

In some embodiments, the powertrain includes a motor/generator operably coupled to the first sun gear.

In some embodiments, the powertrain includes a motor/generator operably coupled to the second sun gear.

In some embodiments, the powertrain includes a motor/generator operably coupled to the planet carrier.

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

Novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention 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 lever diagram of a powertrain having a ball-type variator, an engine, and a ravigneaux gear set.

Figure 5 is a schematic lever diagram of a powertrain having a ball-type variator, an engine, a ravigneaux gear set, and three clutches.

Figure 6 is a table depicting modes of operation of the powertrain of Figure 5.

Figure 7 is a schematic lever diagram of a powertrain having a powersplit ball-type variator, an engine, and a ravigneaux gear set.

Figure 8 is a schematic lever diagram of an electric powertrain having a ball-type variator, an engine, a motor/generator, and a ravigneaux gear set.

Figure 9 is a schematic lever diagram of another electric powertrain having a ball-type variator, an engine, a motor/generator, and a ravigneaux gear set.

Figure 10 is a schematic lever diagram of yet another electric powertrain having a ball-type variator, an engine, a motor/generator, and a ravigneaux gear set.

Figure 11 is a schematic lever diagram of a powertrain having a variator, an engine, and a ravigneaux gear set.

Figure 12 is a schematic lever diagram of a powertrain having a variator, an engine, a ravigneaux gear set, and three clutches.

Figure 13 is a table depicting modes of operation of the powertrain of Figure 12.

Figure 14 is a schematic lever diagram of a powertrain having a powersplit variator, an engine, and a ravigneaux gear set.

Figure 15 is a schematic lever diagram of an electric powertrain having a variator, an engine, a motor/generator, and a ravigneaux gear set.

Figure 16 is a schematic lever diagram of another electric powertrain having a variator, an engine, a motor/generator, and a ravigneaux gear set.

Figure 17 is a schematic lever diagram of yet another electric powertrain having a variator, an engine, a motor/generator, and a ravigneaux gear set.

Figure 18 is a schematic diagram of an exemplary full toroidal variator.

Figure 19 is a schematic diagram of an exemplary half toroidal variator.

Figure 20 is schematic diagram of an exemplary belt-and-pulley variator.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Provided herein are powertrain configurations and architectures that can be used in hybrid vehicles. In some embodiments, the powertrain and/or drivetrain configurations use a ball planetary style continuously variable transmission, such as the VariGlide®, in order to couple power sources used in a hybrid vehicle, for example, combustion engines (internal or external), motors, generators, batteries, and gearing.

A typical ball planetary variator CVT design, such as that described in United States Patent Publication No. 2008/0121487 and in United States Patent No. 8,469,856, both incorporated herein by reference in their entirety, represents a rolling traction drive system, transmitting forces between the input and output rolling surfaces through shearing of a thin fluid film. The technology is called Continuously Variable Planetary (CVP) due to its analogous operation to a planetary gear system. The system includes an input disc (ring) driven by the power source, an output disc (ring) driving the CVP output, a set of balls fitted between these two discs and a central sun, as illustrated in Figure 1. The balls are able to rotate around their own respective axle by the rotation of two carrier disks at each end of the set of balls axles. The system is also referred to as the Ball-Type Variator.

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 of the invention. Furthermore, embodiments of the invention 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.

Provided herein are configurations of CVTs based on a ball-type variators, also known as 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, includes a number of balls (planets, spheres) 1, depending on the application, two ring (disc) assemblies with a conical surface contact with the balls, as input (first)2 and output (second) 3, and an idler (sun) assembly 4 as shown on FIG. 1. Sometimes, the input ring 2 is referred to in illustrations and referred to in text by the label "R1". The output ring is referred to in illustrations and referred to in text by the label "R2". The idler (sun) assembly is referred to in illustrations and referred to in text by the label "S". 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. Sometimes, the carrier assembly is denoted in illustrations and referred to in text by the label "C". These labels are collectively referred to as nodes ("R1", "R2", "S", "C"). 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 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 achieve a desired ratio of input speed to output speed during operation of the CVT.

In some embodiments, adjustment of the axles 5 involves control of the position of the first and second carrier members to impart a tilting of the axles 5 and thereby adjusts the speed ratio of the variator. Other types of ball CVTs also exist, like the one produced by Milner, but are slightly different.

The working principle of such a CVP of FIG. 1 is shown on FIG. 3. The CVP itself works with a traction fluid. The lubricant 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 input and output. When the axis is horizontal the ratio is one, illustrated in FIG. 3, when the axis is tilted the distance between the axis and the contact point change, modifying the overall ratio. All the balls' axes are tilted at the same time with a mechanism included in the carrier and/or idler. Embodiments disclosed herein are related to the control of a variator and/or a CVT using generally spherical planets each having a tiltable axis of rotation that is 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 misalignment 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. The 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 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.

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 is capable of taking 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 will 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 are capable of operating 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.

Embodiments disclosed herein are directed to hybrid vehicle powertrains and/or configurations that incorporate a CVP in place of a regular fixed ratio planetary leading to a continuously variable parallel hybrid. It should be appreciated that the embodiments disclosed herein are adapted to provide hybrid modes of operation that include, but are not limited to parallel or EV (electric vehicle) modes. The core element of the power flow is a CVP, such as a VariGlide, which functions as a continuously variable transmission having four of nodes (R1, R2, C, and S), wherein the carrier (C) is grounded, the rings (R1 and R2) are available for output power, and the sun (S) providing a variable ratio, and, in some embodiments, an auxiliary drive system. The CVP enables the engine (ICE) and electric machines (motor/generators, among others) to run at an optimized overall efficiency.

It should be noted that hydro-mechanical components such as hydromotors, pumps, accumulators, among others, are capable of being used in place of the electric machines indicated in the figures and accompanying textual description. Furthermore, it should be noted that embodiments of hybrid architectures disclosed herein incorporate a hybrid supervisory controller that chooses the path of highest efficiency from engine to wheel. Embodiments disclosed herein enable hybrid powertrains that are capable of operating at the best potential overall efficiency point in any mode and also provide torque variability, thereby leading to the optimal combination of powertrain performance and fuel efficiency. It should be understood that hybrid vehicles incorporating embodiments of the hybrid architectures disclosed herein are capable of including a number of other powertrain components, such as, but not limited to, high-voltage battery pack with a battery management system or ultracapacitor, on-board charger, DC-DC converters, a variety of sensors, actuators, and controllers, among others.

For purposes of description, schematics referred to as lever diagrams are used herein. A lever diagram, also known as a lever analogy diagram, is a translational-system representation of rotating parts for a planetary gear system. In certain embodiments, a lever diagram is provided as a visual aid in describing the functions of the transmission. In a lever diagram, a compound planetary gear set is often represented by a single vertical line ("lever"). The input, output, and reaction torques are represented by horizontal forces on the lever. The lever motion, relative to the reaction point, represents direction of rotational velocities. For example, a typical planetary gear set having a ring gear, a planet carrier, and a sun gear is represented by a vertical line having nodes "R" representing the ring gear, node "S" representing the sun gear, and node "C" representing the planet carrier.

Referring to FIG. 4, in some embodiments, a powertrain 20 includes an engine 21 and a variator (CVP) 22 having a first traction ring assembly 23, a second traction ring assembly 24, and a carrier 25. In some embodiments, the CVP 22 is of the type depicted in FIGS. 1-3.

The powertrain 20 includes a ravigneaux gear set 26. In some embodiments, the ravigneaux gear set 26 includes a ravigneaux planet carrier 28 configured to support two sets of planet gears coupled to a common ring gear 27. A first ravigneaux sun gear 29 couples to a first set of planet gears. A second ravigneaux sun gear 30 couples to a second set of planet gears.

In some embodiments, the first traction ring assembly 23 is operably coupled to the engine 21. The second traction ring assembly 24 is operably coupled to the first ravigneaux sun gear 29. During operation of the powertrain 20, a rotational power is transmitted out of the ring gear 27.

Referring to FIG. 5, in some embodiments, a powertrain 35 includes an engine 36 and a variator (CVP) 37 having a first traction ring assembly 38, a second traction ring assembly 39, and a carrier 40. In some embodiments, the CVP 37 is of the type depicted in FIGS. 1-3.

The powertrain 35 includes a ravigneaux gear set 41. In some embodiments, the ravigneaux gear set 41 includes a ravigneaux planet carrier 43 configured to support two sets of planet gears coupled to a common ring gear 42. A first ravigneaux sun gear 44 couples to a first set of planet gears. A second ravigneaux sun gear 45 couples to a second set of planet gears.

In some embodiments, the first traction ring assembly 38 is operably coupled to the engine 36. The second traction ring assembly 39 is operably coupled to the first ravigneaux sun gear 44.

In some embodiments, the powertrain 35 includes a first mode clutch 46 configured to selectively couple the second ravigneaux sun gear 45 to a grounded member (not shown) of the powertrain 35. The powertrain 35 includes a second mode clutch 47 operably coupled to the first ravigneaux sun gear 44 and the second ravigneaux sun gear 45. The powertrain 35 includes a reverse clutch 48 configured to selectively couple the ravigneaux planet carrier 43 to a grounded member (not shown).

Turning to FIG. 6, during operation of the powertrain 35, a rotational power is transmitted from the ring gear 42. Multiple modes of operation are achieved through control of the first mode clutch 46, the second mode clutch 47, and the reverse clutch 48. Engagement of the first mode clutch 46 and disengagement of the second mode clutch 47 and the reverse clutch 48 corresponds to a first mode of operation having a first forward speed range. Engagement of the second mode clutch 47 and disengagement of the first mode clutch 46 and reverse clutch 48 corresponds to a second mode of operation having a second forward speed range. In some embodiments, the second forward speed range includes vehicle speeds that are higher than the first forward speed range. Engagement of the reverse clutch 48 and disengagement of the first mode clutch 46 and the second mode clutch 47 corresponds to a reverse mode of operation having a speed range in the reverse direction.

Referring now to FIG. 7, in some embodiments, a powersplit powertrain 50 includes an engine 51 and a variator (CVP) 52 having a first traction ring assembly 53, a second traction ring assembly 54, and a carrier 55. In some embodiments, the CVP 52 is of the type depicted in FIGS. 1-3.

The powersplit powertrain 50 includes a first planetary gear set 56 having a first ring gear 57 operable coupled to the first traction ring assembly 53, a first planet carrier 58 operably coupled the engine 51, and a first sun gear 59 operably coupled to the second traction ring assembly 54.

The powertrain 50 includes a ravigneaux gear set 60. In some embodiments, the ravigneaux gear set 60 includes a ravigneaux planet carrier 61 configured to support two sets of planet gears coupled to a common ring gear 64. A first ravigneaux sun gear

62 couples to a first set of planet gears. A second ravigneaux sun gear 63 couples to a second set of planet gears.

In some embodiments, the second traction ring assembly 54 is operably coupled to the first sun gear 59. The second traction ring assembly 54 is operably coupled to the first ravigneaux sun gear 62. During operation of the powersplit powertrain 50, a rotational power is transmitted from the common ring gear 64.

Referring now to FIG. 8, in some embodiments, an electric hybrid powertrain 70 includes an engine 71 and a variator (CVP) 72 having a first traction ring assembly 73, a second traction ring assembly 74, and a carrier 75. In some embodiments, the CVP 72 is of the type depicted in FIGS. 1-3.

The electric hybrid powertrain 70 includes a ravigneaux gear set 76. In some embodiments, the ravigneaux gear set 76 includes a ravigneaux planet carrier 78 configured to support two sets of planet gears coupled to a common ring gear 77. A first ravigneaux sun gear 79 couples to a first set of planet gears. A second ravigneaux sun gear 80 couples to a second set of planet gears.

In some embodiments, the first traction ring assembly 73 is operably coupled to the engine 71. The second traction ring assembly 74 is operably coupled to the first ravigneaux sun gear 79. The electric hybrid powertrain 70 includes a motor/generator 81 operably coupled to the first ravigneaux sun gear 79. During operation of the electric hybrid powertrain 70, a rotational power is transmitted out of the ring gear 77.

In some embodiments, the electric hybrid powertrain 70 is optionally provided with a disconnect clutch 82 arranged between the engine and the CVP 72. The disconnect clutch 82 is shown in Figure 8 for illustrative example. It should be appreciated that a disconnect clutch is optionally provided for selectively coupling the engine to the CVP in the electric hybrid powertrains disclosed herein.

Referring now to FIG. 9, in some embodiments, an electric hybrid powertrain 90 includes an engine 91 and a variator (CVP) 92 having a first traction ring assembly 93, a second traction ring assembly 94, and a carrier 95. In some embodiments, the CVP 92 is of the type depicted in FIGS. 1-3.

The electric hybrid powertrain 90 includes a ravigneaux gear set 96. In some embodiments, the ravigneaux gear set 96 includes a ravigneaux planet carrier 98 configured to support two sets of planet gears coupled to a common ring gear 97. A first ravigneaux sun gear 99 couples to a first set of planet gears. A second ravigneaux sun gear 100 couples to a second set of planet gears.

In some embodiments, the first traction ring assembly 93 is operably coupled to the engine 91. The second traction ring assembly 94 is operably coupled to the first ravigneaux sun gear 99. The electric hybrid powertrain 90 includes a motor/generator 101 operably coupled to the second ravigneaux sun gear 100. During operation of the electric hybrid powertrain 90, a rotational power is transmitted out of the ring gear 97.

In some embodiments, the electric hybrid powertrain 90 is optionally provided with a disconnect clutch (not shown) arranged between the engine and the CVP 92.

Referring now to FIG. 10, in some embodiments, an electric hybrid powertrain 110 includes an engine 111 and a variator (CVP) 112 having a first traction ring assembly 113, a second traction ring assembly 114, and a carrier 115. In some embodiments, the CVP 112 is of the type depicted in FIGS. 1-3.

The electric hybrid powertrain 110 includes a ravigneaux gear set 116. In some embodiments, the ravigneaux gear set 116 includes a ravigneaux planet carrier 118 configured to support two sets of planet gears coupled to a common ring gear 117. A first ravigneaux sun gear 119 couples to a first set of planet gears. A second ravigneaux sun gear 120 couples to a second set of planet gears.

In some embodiments, the first traction ring assembly 113 is operably coupled to the engine 111. The second traction ring assembly 114 is operably coupled to the first ravigneaux sun gear 119. The electric hybrid powertrain 110 includes a motor/generator 121 operably coupled to the ravigneaux planet carrier 118. During operation of the electric hybrid powertrain 110, a rotational power is transmitted out of the ring gear 117.

In some embodiments, the electric hybrid powertrain 110 is optionally provided with a disconnect clutch (not shown) arranged between the engine and the CVP 112. Referring to FIG. 11, in some embodiments, a powertrain 130 includes an engine 131 and a variator 132.

In some embodiments, the variator 132 is a full toroidal type continuously variable transmission, for example, of the type depicted in Figure 18.

In some embodiments, the variator 132 is a half toroidal continuously variable transmission, for example, of the type depicted in Figure 19.

In other embodiments, the variator 132 is a belt-and-pulley continuously variable transmission, for example, of the type depicted in Figure 20.

In some embodiments, the powertrain 130 includes a ravigneaux gear set 136. In some embodiments, the ravigneaux gear set 136 includes a ravigneaux planet carrier 138 configured to support two sets of planet gears coupled to a common ring gear 137. A first ravigneaux sun gear 139 couples to a first set of planet gears. A second ravigneaux sun gear 140 couples to a second set of planet gears.

In some embodiments, the variator 132 is operably coupled to the engine 131 to receive an input power. The variator 132 is operably coupled to the first ravigneaux sun gear 29 to transfer rotational power. During operation of the powertrain 130, a rotational power is transmitted out of the ring gear 137.

Referring to FIG. 12, in some embodiments, a powertrain 145 includes an engine 146 and a variator (CVP) 147.

In some embodiments, the variator 147 is a full toroidal type continuously variable transmission, for example, of the type depicted in Figure 18.

In some embodiments, the variator 147 is a half toroidal continuously variable transmission, for example, of the type depicted in Figure 19.

In other embodiments, the variator 147 is a belt-and-pulley continuously variable transmission, for example, of the type depicted in Figure 20.

In some embodiments, the powertrain 145 includes a ravigneaux gear set 151. In some embodiments, the ravigneaux gear set 151 includes a ravigneaux planet carrier 153 configured to support two sets of planet gears coupled to a common ring gear 152. A first ravigneaux sun gear 154 couples to a first set of planet gears. A second ravigneaux sun gear 155 couples to a second set of planet gears.

In some embodiments, the variator 147 is operably coupled to the engine 146. The variator 147 is operably coupled to the first ravigneaux sun gear 154.

In some embodiments, the powertrain 145 includes a first mode clutch 156 configured to selectively coupled the second ravigneaux sun gear 155 to a grounded member (not shown) of the powertrain 145. The powertrain 145 includes a second mode clutch 157 operably coupled to the first ravigneaux sun gear 154 and the second ravigneaux sun gear 155. The powertrain 145 includes a reverse clutch 158 configured to selectively couple the ravigneaux planet carrier 153 to a grounded member (not shown).

Turning to FIG. 13, during operation of the powertrain 145, a rotational power is transmitted from the ring gear 152. Multiple modes of operation are achieved through control of the first mode clutch 156, the second mode clutch 157, and the reverse clutch 158. Engagement of the first mode clutch 156 and disengagement of the second mode clutch 157 and the reverse clutch 158 corresponds to a first mode of operation having a first forward speed range. Engagement of the second mode clutch 157 and disengagement of the first mode clutch 156 and reverse clutch 158 corresponds to a second mode of operation having a second forward speed range. Engagement of the reverse clutch 158 and disengagement of the first mode clutch 156 and the second mode clutch 157 corresponds to a reverse mode of operation having a speed range in the reverse direction.

Referring now to FIG. 14, in some embodiments, a powersplit powertrain 160 includes an engine 161 and a variator 162.

In some embodiments, the variator 162 is a full toroidal type continuously variable transmission, for example, of the type depicted in Figure 18.

In some embodiments, the variator 162 is a half toroidal continuously variable transmission, for example, of the type depicted in Figure 19.

In other embodiments, the variator 162 is a belt-and-pulley continuously variable transmission, for example, of the type depicted in Figure 20.

In some embodiments, the powersplit powertrain 160 includes a first planetary gear set 166 having a first ring gear 167 operable coupled to an input member of the variator 162, a first planet carrier 168 operably coupled the engine 161, and a first sun gear 169 operably coupled to an output member of the variator 162.

In some embodiments, the powertrain 160 includes a ravigneaux gear set 170. In some embodiments, the ravigneaux gear set 170 includes a ravigneaux planet carrier 171 configured to support two sets of planet gears coupled to a common ring gear 174. A first ravigneaux sun gear 172 couples to a first set of planet gears. A second ravigneaux sun gear 173 couples to a second set of planet gears.

In some embodiments, the variator 162 is operably coupled to the first sun gear 169. The variator 162 is operably coupled to the first ravigneaux sun gear 172. During operation of the powersplit powertrain 160, a rotational power is transmitted from the common ring gear 174.

Referring now to FIG. 15, in some embodiments, an electric hybrid powertrain 180 includes an engine 181 and a variator 182.

In some embodiments, the variator 182 is a full toroidal type continuously variable transmission, for example, of the type depicted in Figure 18.

In some embodiments, the variator 182 is a half toroidal continuously variable transmission, for example, of the type depicted in Figure 19.

In other embodiments, the variator 182 is a belt-and-pulley continuously variable transmission, for example, of the type depicted in Figure 20.

In some embodiments, the electric hybrid powertrain 180 includes a ravigneaux gear set 186. In some embodiments, the ravigneaux gear set 186 includes a planet carrier 188 configured to support two sets of planet gears coupled to a common ring gear 187. A first ravigneaux sun gear 189 couples to a first set of planet gears. A second ravigneaux sun gear 190 couples to a second set of planet gears.

In some embodiments, the variator 182 is operably coupled to the engine 71. The variator 182 is operably coupled to the first ravigneaux sun gear 189. The electric hybrid powertrain 180 includes a motor/generator 191 operably coupled to the first ravigneaux sun gear 189. During operation of the electric hybrid powertrain 180, a rotational power is transmitted out of the ring gear 187.

In some embodiments, the electric hybrid powertrain 180 is optionally provided with a disconnect clutch (not shown) arranged between the engine and the variator 182.

Referring now to FIG. 16, in some embodiments, an electric hybrid powertrain 200 includes an engine 201 and a variator 202.

In some embodiments, the variator 202 is a full toroidal type continuously variable transmission, for example, of the type depicted in Figure 18.

In some embodiments, the variator 202 is a half toroidal continuously variable transmission, for example, of the type depicted in Figure 19.

In other embodiments, the variator 202 is a belt-and-pulley continuously variable transmission, for example, of the type depicted in Figure 20.

The powertrain 200 includes a ravigneaux gear set 206. In some embodiments, the ravigneaux gear set 206 includes a ravigneaux planet carrier 208 configured to support two sets of planet gears coupled to a common ring gear 207. A first ravigneaux sun gear 209 couples to a first set of planet gears. A second ravigneaux sun gear 210couples to a second set of planet gears.

In some embodiments, the variator 202 is operably coupled to the engine 201. The variator 202 is operably coupled to the first ravigneaux sun gear 209. The electric hybrid powertrain 200 includes a motor/generator 211 operably coupled to the second ravigneaux sun gear 210. During operation of the electric hybrid powertrain 200, a rotational power is transmitted out of the ring gear 207.

In some embodiments, the electric hybrid powertrain 200 is optionally provided with a disconnect clutch (not shown) arranged between the engine and the variator 202.

Referring now to FIG. 17, in some embodiments, an electric hybrid powertrain 220 includes an engine 221 and a variator 222.

In some embodiments, the variator 222 is a full toroidal type continuously variable transmission, for example, of the type depicted in Figure 18.

In some embodiments, the variator 22 is a half toroidal continuously variable transmission, for example, of the type depicted in Figure 19.

In other embodiments, the variator 22 is a belt-and-pulley continuously variable transmission, for example, of the type depicted in Figure 20.

In some embodiments, the electric hybrid powertrain 220 includes a ravigneaux gear set 226. In some embodiments, the ravigneaux gear set 226 includes a ravigneaux planet carrier 228 configured to support two sets of planet gears coupled to a common ring gear 227. A first ravigneaux sun gear 229 couples to a first set of planet gears. A second ravigneaux sun gear 230 couples to a second set of planet gears.

In some embodiments, the variator 222 is operably coupled to the engine 221. The variator 222 is operably coupled to the first ravigneaux sun gear 229. The electric hybrid powertrain 220 includes a motor/generator 231 operably coupled to the ravigneaux planet carrier 228. During operation of the electric hybrid powertrain 220, a rotational power is transmitted out of the ring gear 227.

In some embodiments, the electric hybrid powertrain 220 is optionally provided with a disconnect clutch (not shown) arranged between the engine and the variator 222.

Referring now to FIG. 18, as an illustrative example of a full toroidal continuously variable transmission, a full toroidal variator 500 is provided with an input shaft 501 coupled to a first traction disc 502. The first traction disc 502 is provided with a first curved raceway 503 adapted to engage a number of traction rollers 504. Each traction roller 504 is provided with a tiltable axis of rotation. The full toroidal variator 500 is provided with a second traction disc 505 having a second curved raceway 506. The first curved raceway 506 and the second curved raceway 507 may take on a variety of shapes, and are semicircular when viewed in the plane of the page of figure 9. The second traction disc 505 is coupled to a shaft 507. Since the direction of rotation of the input shaft 501 is opposite of the direction of rotation of the shaft 507, a transfer gear set 508 is coupled to the shaft 507 to transmit power to an output shaft 509. The output shaft 509 rotates in the same direction as the input shaft 501.

Referring now to FIG. 19, as an illustrative example of a half toroidal continuously variable transmission, a half toroidal variator 550 is provided with an input shaft 551 coupled to a first traction disc 552. The first traction disc 552 is provided with a first curved raceway 553 adapted to engage a number of traction rollers 554. Each traction roller 554 is provided with a tiltable axis of rotation. The full toroidal variator 550 is provided with a second traction disc 555 having a second curved raceway 556. The first curved raceway 556 and the second curved raceway 557 may take on a variety of shapes, and are quartercircular when viewed in the plane of the page of Figure 19. The second traction disc 555 is coupled to a shaft 557. Since the direction of rotation of the input shaft 551 is opposite of the direction of rotation of the shaft 557, a transfer gear set 558 is coupled to the shaft 557 to transmit power to an output shaft 559. The output shaft 559 rotates in the same direction as the input shaft 351.

Referring now to FIG. 20, as an illustrative example of a belt-and-pulley type of continuously variable transmission, a belt-and-pulley variator 400 includes an input shaft 401, a first pulley 402 coupled to a second pulley 404 with a belt 403. An output shaft 405 is coupled to the second pulley 404. During operation, adjustment of the engagement surface between the belt 403 and the first pulley 401, and in some embodiments, the second pulley 404, through a range 406 provides a variable ratio of operating speed between the input shaft 401 and the output shaft 405. The input shaft 401 and the output shaft 405 have the same direction of rotation.

It should be understood that additional clutches/brakes, step ratios are optionally provided to the hybrid powertrains disclosed herein to obtain varying powerpath characteristics. It should be noted that, in some embodiments, two or more planetary gears and a variator are optionally configured to provide a desired speed ratio range and operating mode to the electric machine. It should be noted that the connections of the engine and the electric machine to the powerpaths disclosed herein are provided for illustrative example and it is within a designer's means to couple the engine and electric machine to other components of the powertrains disclosed herein.

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

While preferred embodiments of the present invention 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 invention. It should be understood that various alternatives to the embodiments of the invention described herein are capable of being employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

Aspects of the inventions include:

Aspect 1. A powertrain comprising:

an engine;

a continuously variable planetary transmission (CVP) having a plurality of balls, each ball provided with a tiltable axis of rotation, each ball in contact with a first traction ring assembly and a second traction ring assembly, and each ball operably coupled to a carrier; and

a ravigneaux gear set having a common ring gear, a ravigneaux planet carrier supporting a first set of planet gears coupled to the common ring gear and a second set of planet gears coupled to the common ring gear, a first ravigneaux sun gear coupled to the first set of the planet gears, a second ravigneaux sun gear coupled to the second set of the planet gears, wherein the engine is operably coupled to the first traction ring assembly and the second traction ring assembly is coupled to the first ravigneaux sun gear.

Aspect 2. The powertrain of Aspect 1, wherein the common ring gear is adapted to transmit power from the powertrain.

Aspect 3. The powertrain of Aspect 1, further comprising a first mode clutch configured to selectively couple the second ravigneaux sun gear to ground.

Aspect 4. The powertrain of Aspect 1, further comprising a second mode clutch configured to selectively couple the first ravigneaux sun gear to the second ravigneaux sun gear.

Aspect 5. The powertrain of Aspect 5, further comprising a reverse clutch configured to selectively couple the ravigneaux planet carrier to ground.

Aspect 6. The powertrain of Aspect 1, further comprising a motor/generator operably coupled to the first ravigneaux sun gear.

Aspect 7. The powertrain of Aspect 1, further comprising a motor/generator operably coupled to the second ravigneaux sun gear.

Aspect 8. The powertrain of Aspect 1, further comprising a motor/generator operably coupled to the planet ravigneaux carrier.

Aspect 9. A powertrain comprising:

an engine;

a continuously variable planetary transmission (CVP) having a plurality of balls, each ball provided with a tiltable axis of rotation, each ball in contact with a first traction ring assembly and a second traction ring assembly, and each ball operably coupled to a carrier;

a planetary gear set having a first ring gear operably coupled to the first traction ring assembly, a first planet carrier operably to the engine, and a first sun gear operably coupled to the second traction ring assembly; and

a ravigneaux gear set having a common ring gear, a ravigneaux planet carrier supporting a first set of planet gears coupled to the common ring gear and a second set of planet gears coupled to the common ring gear, a first ravigneaux sun gear coupled to the first set of the planet gears, a second ravigneaux sun gear coupled to the second set of the planet gears,

wherein the first sun gear is operably coupled to the first ravigneaux sun gear.

Aspect 10. The powertrain of Aspect 9, further comprising a motor/generator operably coupled to the first sun gear.

Aspect 11. The powertrain of Aspect 9, further comprising a motor/generator operably coupled to the second sun gear.

Aspect 12. The powertrain of Aspect 9, further comprising a motor/generator operably coupled to the planet carrier.

WHAT IS CLAIMED IS:

1. A powertrain comprising:

an engine;

a continuously variable planetary transmission (CVP) having a plurality of balls, each ball provided with a tiltable axis of rotation, each ball in contact with a first traction ring assembly and a second traction ring assembly, and each ball operably coupled to a carrier; and

a ravigneaux gear set having a common ring gear, a ravigneaux planet carrier supporting a first set of planet gears coupled to the common ring gear and a second set of planet gears coupled to the common ring gear, a first ravigneaux sun gear coupled to the first set of the planet gears, a second ravigneaux sun gear coupled to the second set of the planet gears,

wherein the engine is operably coupled to the first traction ring assembly and the second traction ring assembly is coupled to the first ravigneaux sun gear.

2. The powertrain of Claim 1, wherein the common ring gear is adapted to transmit power from the powertrain.

3. The powertrain of Claim 2, further comprising a first mode clutch configured to selectively couple the second ravigneaux sun gear to ground.

4. The powertrain of Claim 3, further comprising a second mode clutch configured to selectively couple the first ravigneaux sun gear to the second ravigneaux sun gear.

5. The powertrain of Claim 4, further comprising a reverse clutch configured to selectively couple the ravigneaux planet carrier to ground.

6. The powertrain of Claim 1, further comprising a motor/generator operably coupled to the first ravigneaux sun gear.

7. The powertrain of Claim 1, further comprising a motor/generator operably coupled to the second ravigneaux sun gear.

8. The powertrain of Claim 1, further comprising a motor/generator operably coupled to the planet ravigneaux carrier.

9. A powertrain comprising:

an engine;

a continuously variable planetary transmission (CVP) having a plurality of balls, each ball provided with a tiltable axis of rotation, each ball in contact with a first traction ring assembly and a second traction ring assembly, and each ball operably coupled to a carrier;

a planetary gear set having a first ring gear operably coupled to the first traction ring assembly, a first planet carrier operably to the engine, and a first sun gear operably coupled to the second traction ring assembly; and

a ravigneaux gear set having a common ring gear, a ravigneaux planet carrier supporting a first set of planet gears coupled to the common ring gear and a second set of planet gears coupled to the common ring gear, a first ravigneaux sun gear coupled to the first set of the planet gears, a second ravigneaux sun gear coupled to the second set of the planet gears,

wherein the first sun gear is operably coupled to the first ravigneaux sun gear.

10. The powertrain of Claim 9, further comprising a motor/generator operably coupled to the first sun gear.

11. The powertrain of Claim 9, further comprising a motor/generator operably coupled to the second sun gear.

12. The powertrain of Claim 9, further comprising a motor/generator operably coupled to the planet carrier.

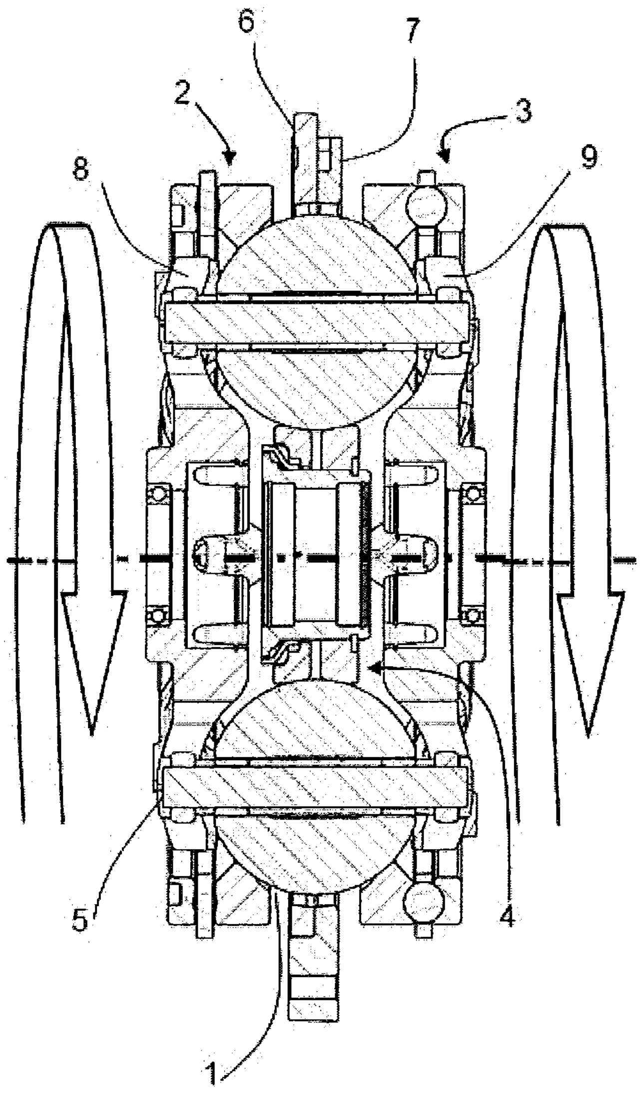

Figure 1

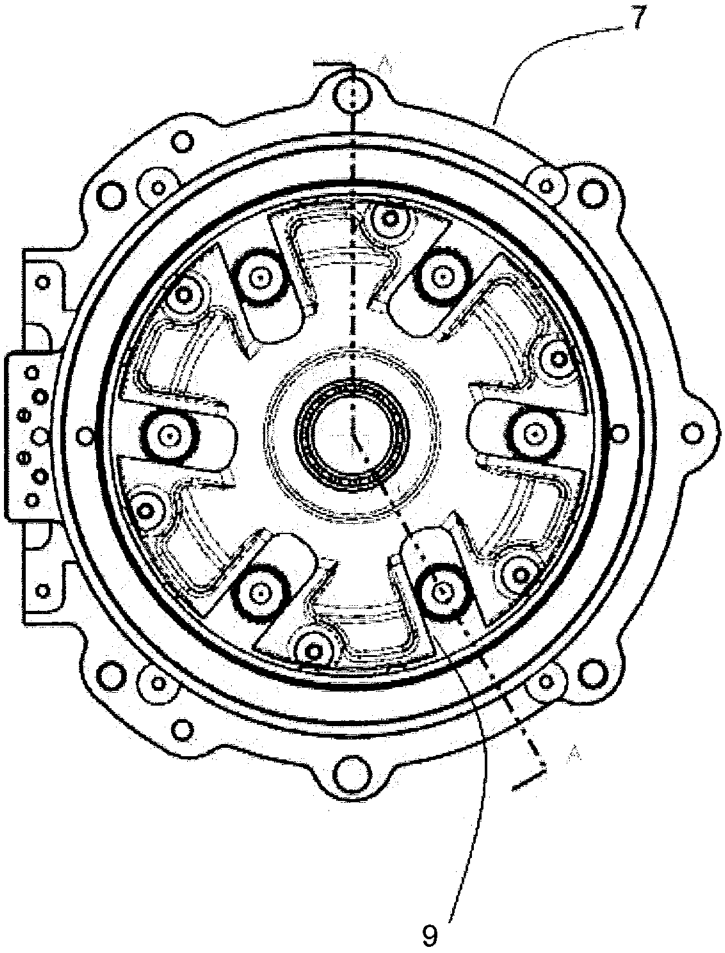

Figure 2

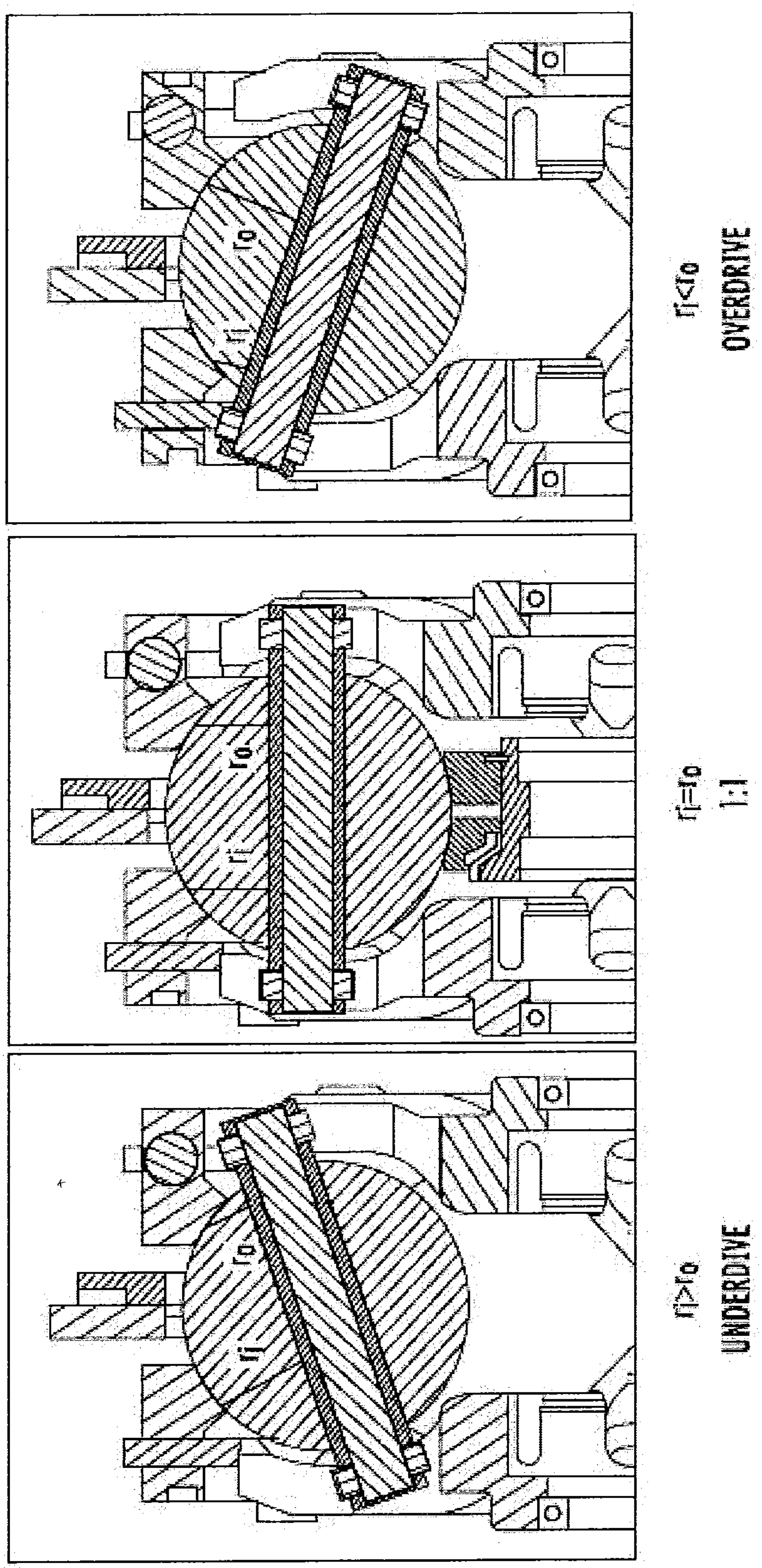

FIG. 3

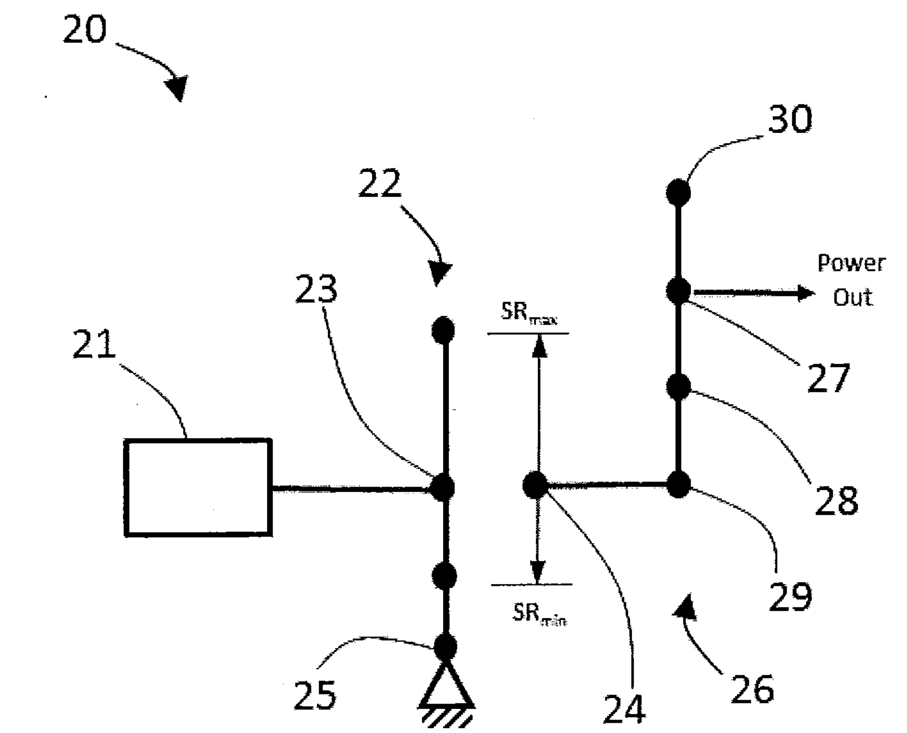

Figure 4

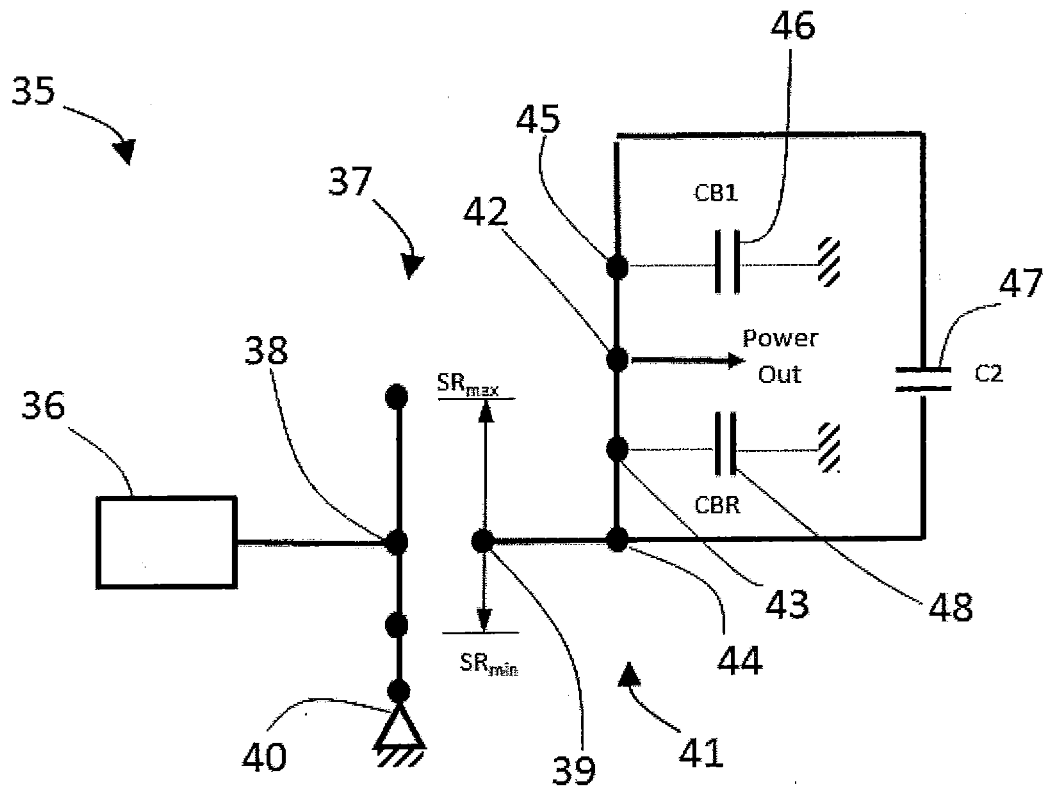

Figure 5

46 47 48

	CB1	CB2	CBR
Mode 1	X		
Mode 2		X	
Reverse			X

Figure 6

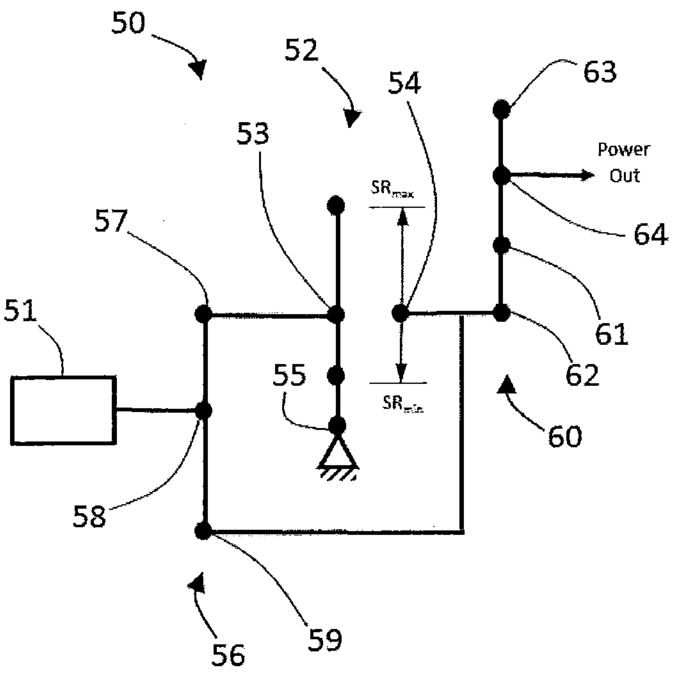

Figure 7

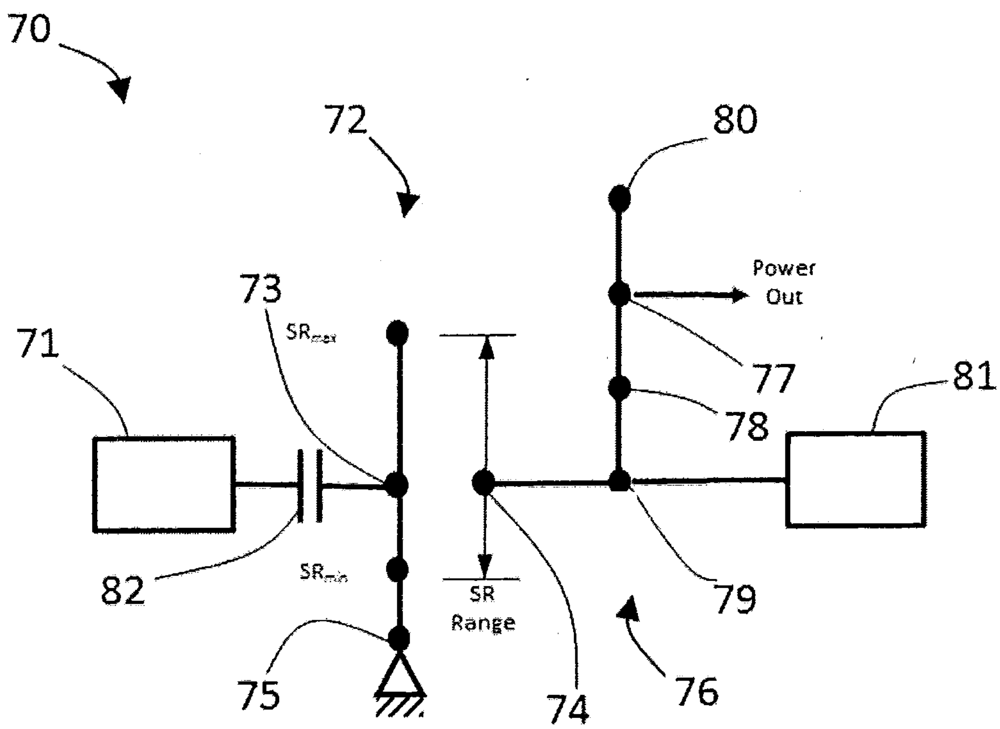

Figure 8

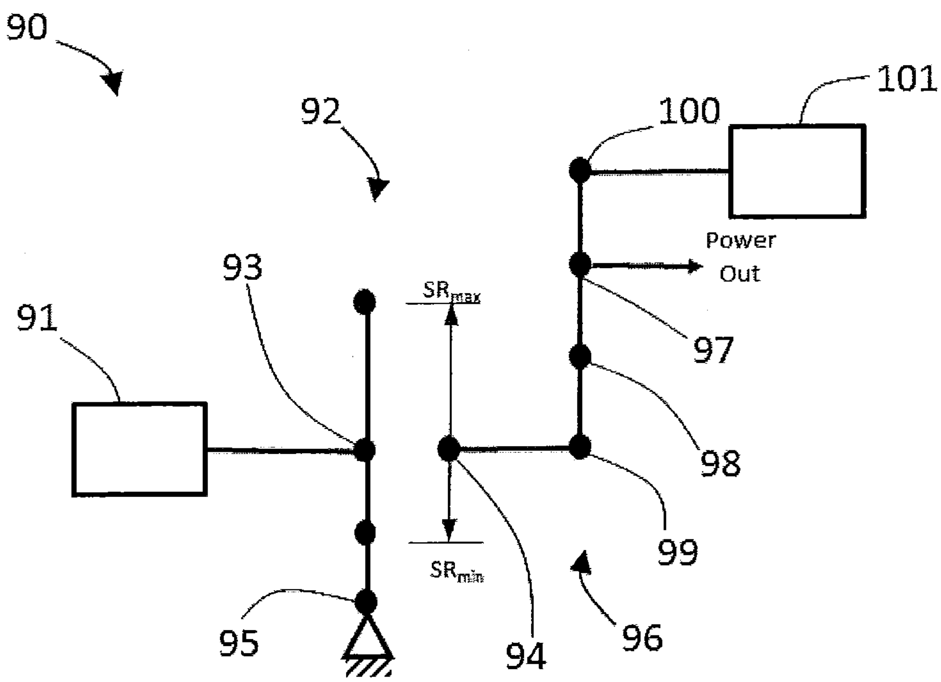

Figure 9

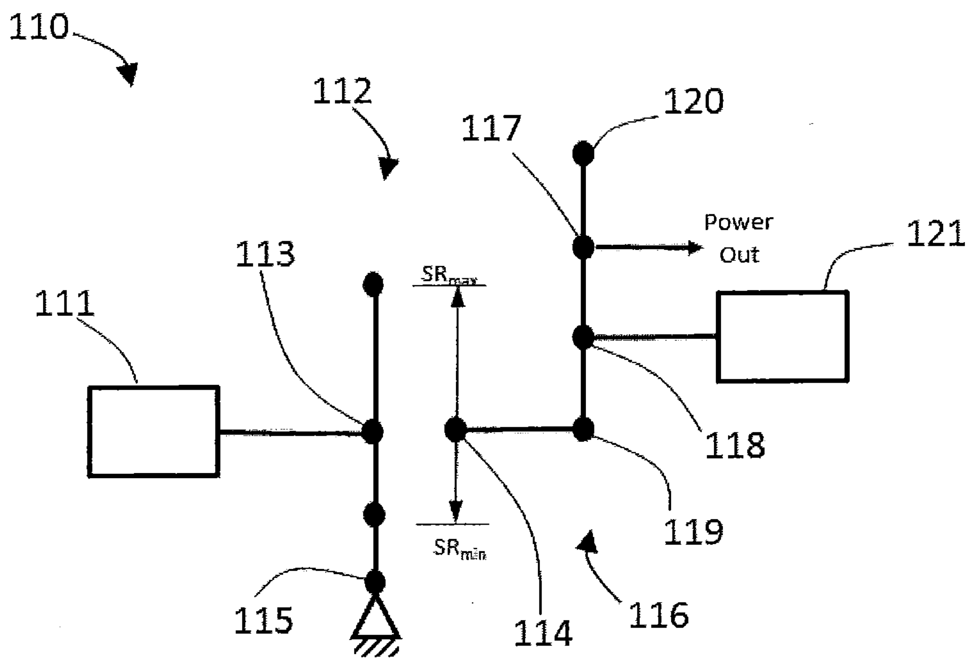

Figure 10

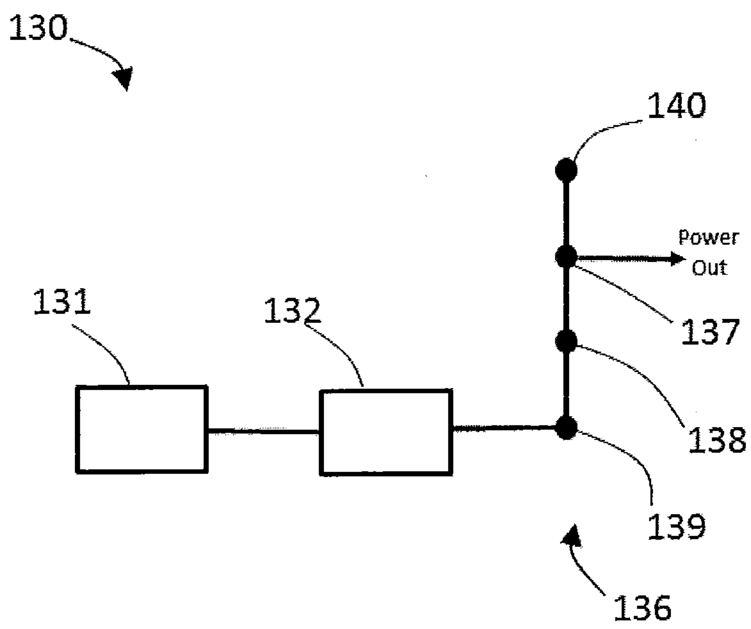

Figure 11

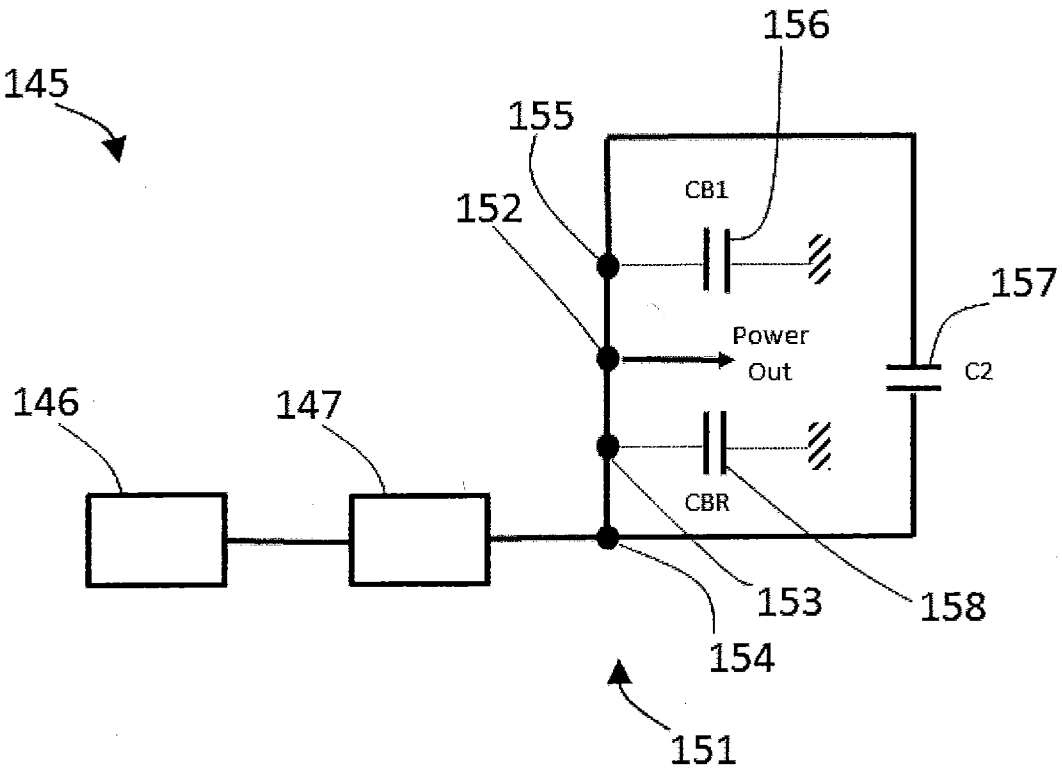

Figure 12

	CB1	CB2	CBR
Mode 1	X		
Mode 2		X	
Reverse			X

Figure 13

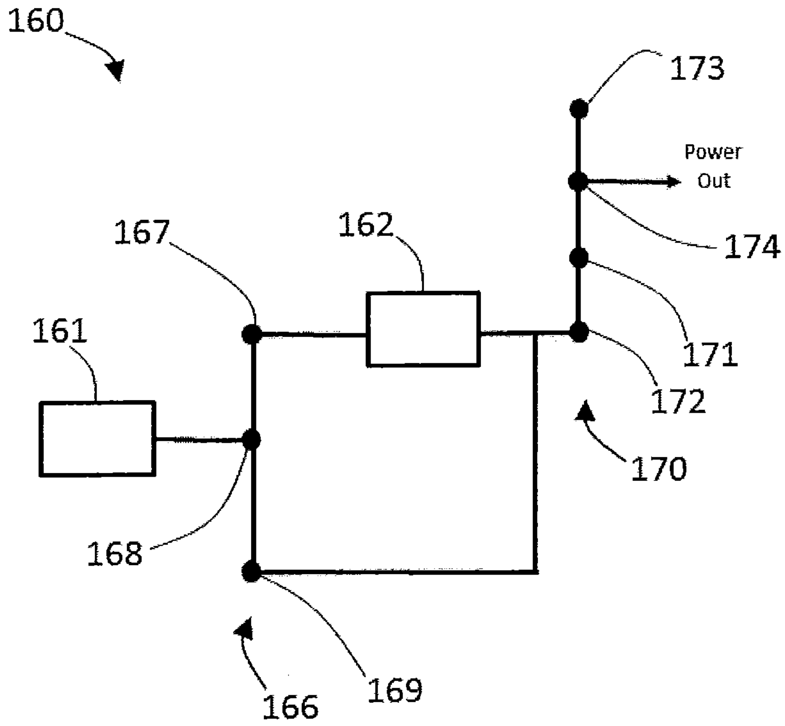

Figure 14

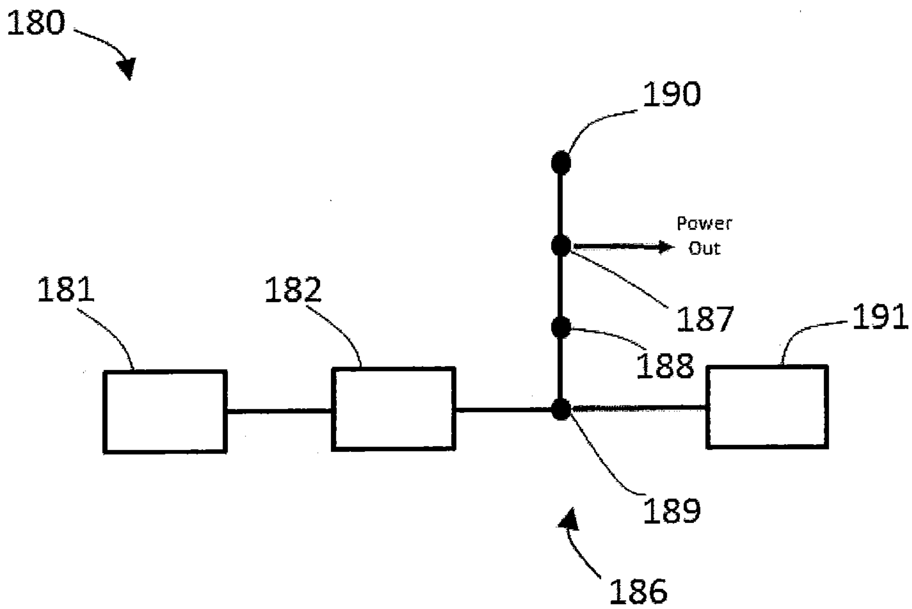

Figure 15

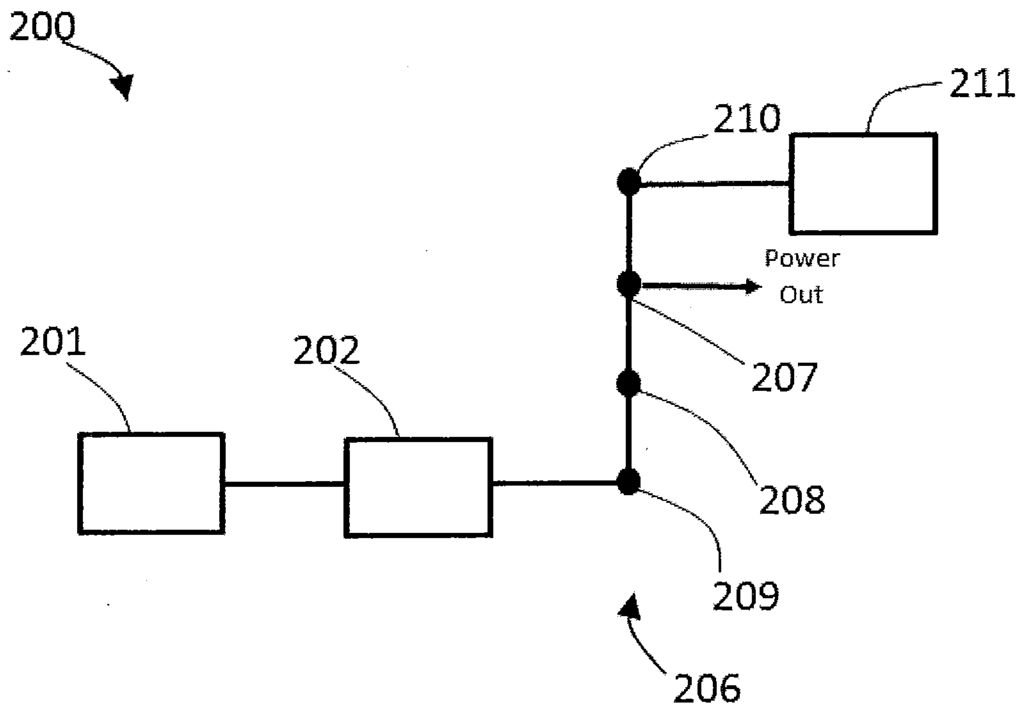

Figure 16

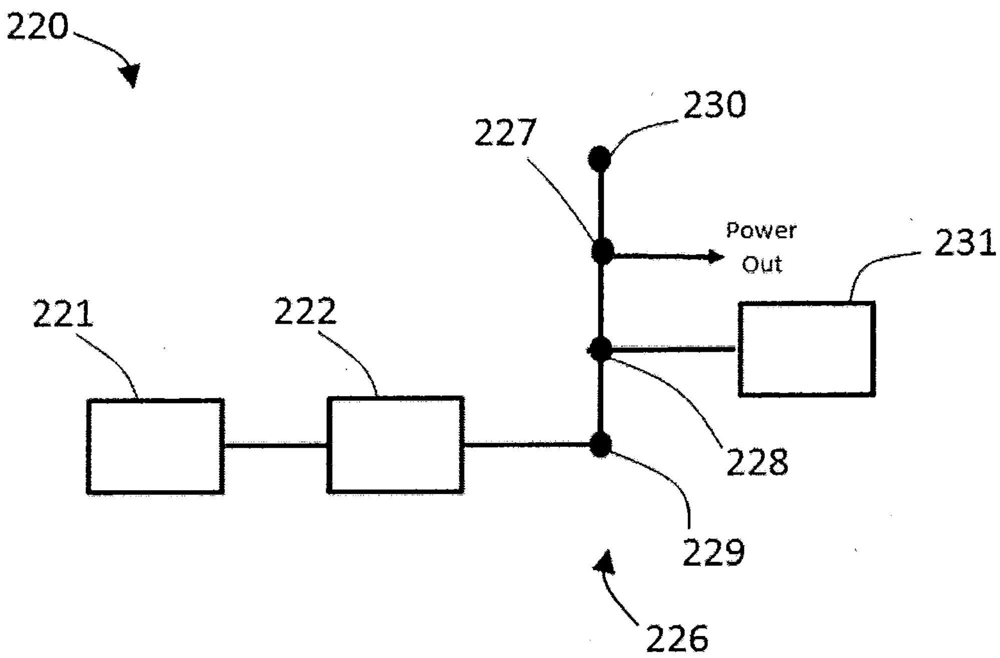

Figure 17

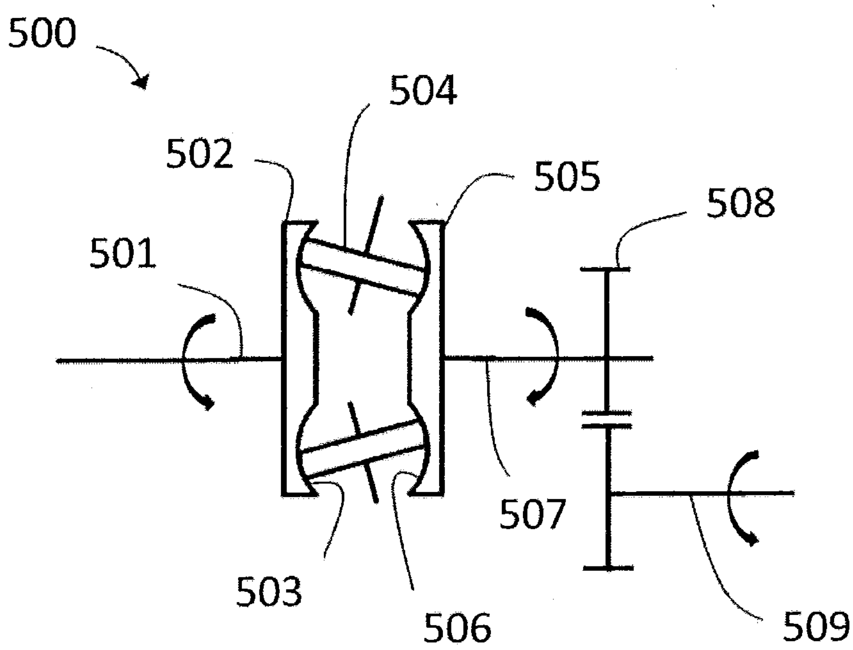

Figure 18

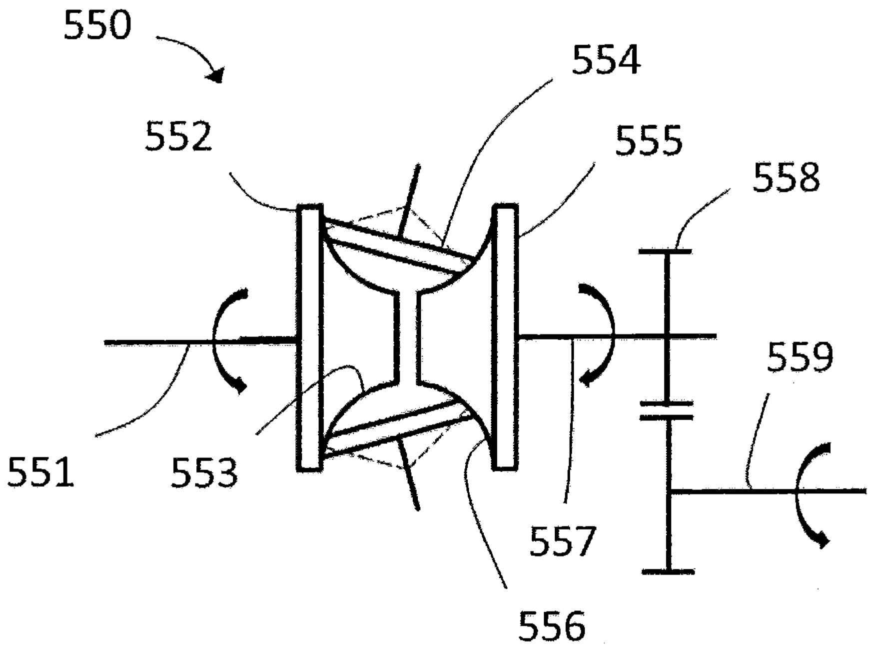

Figure 19

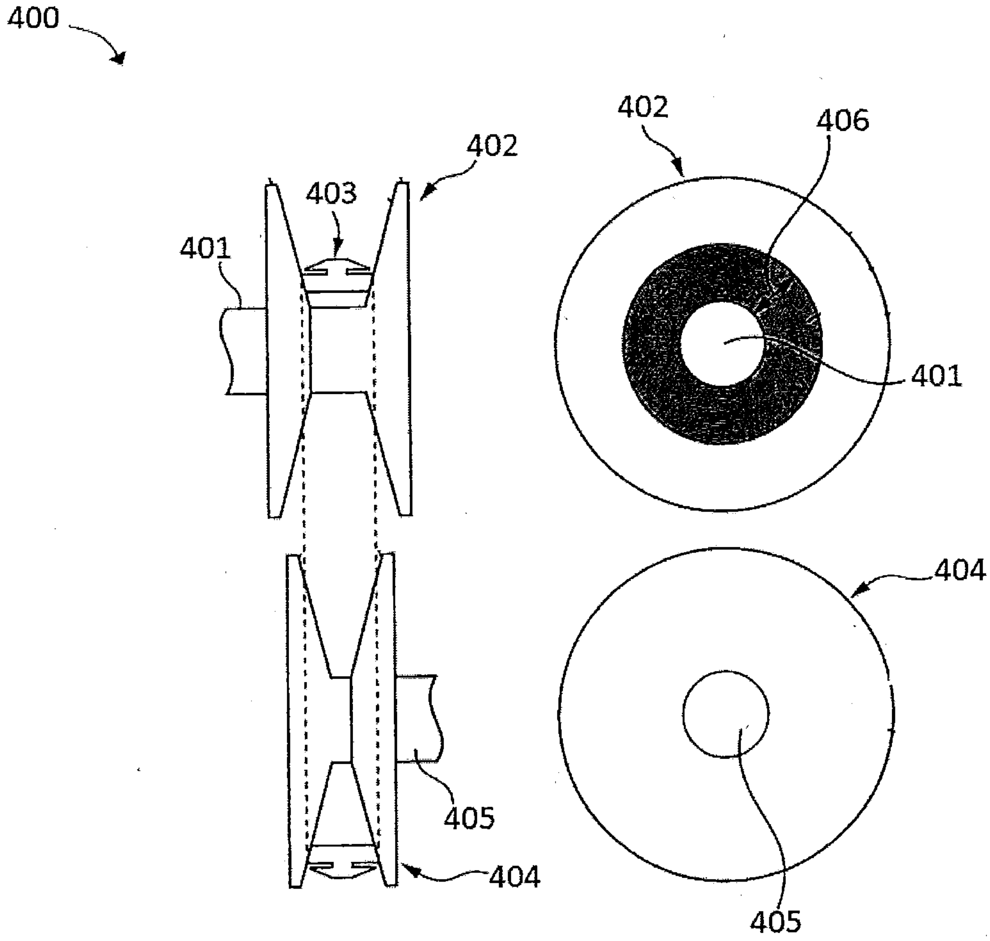

Figure 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/046426

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [X] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-8

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/046426

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16H3/66 F16H15/28 F16H37/08
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 Y	WO 2016/094254 A1 (DANA LTD [US]) 16 June 2016 (2016-06-16) paragraphs [0002], [0012], [0048], [0057], [0065]; figure 1	1-5 6-8
X	WO 2014/039439 A1 (DANA LTD [US]) 13 March 2014 (2014-03-13) paragraphs [0030] - [0036]; figure 6	1
Y	US 7 238 139 B2 (FORD GLOBAL TECH INC [US]) 3 July 2007 (2007-07-03) figures 2, 3	6-8

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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	Date of mailing of the international search report
23 October 2018	03/01/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Martínez Hurtado, L

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2018/046426

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2016094254 A1	16-06-2016	CN 107110303 A	29-08-2017
		JP 2017537285 A	14-12-2017
		WO 2016094254 A1	16-06-2016
WO 2014039439 A1	13-03-2014	CN 104769328 A	08-07-2015
		JP 6320386 B2	09-05-2018
		JP 2015527551 A	17-09-2015
		US 2014194242 A1	10-07-2014
		US 2015226299 A1	13-08-2015
		WO 2014039439 A1	13-03-2014
US 7238139 B2	03-07-2007	NONE	

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-8

   Continuously variable planetary transmission that comprises a ravigneau gear set and a planetary gear set.

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2. claims: 9-12

   Continuously variable planetary transmission that comprises a ravigneau gear set and a planetary gear set.
