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(54) Title: PLANETARY POWERTRAIN CONFIGURATIONS WITH A BALL VARIATOR CONTINUOUSLY VARIABLE TRANSMISSION USED AS A POWERSPLIT

(57) Abstract: Devices and methods are provided herein for the transmission of power in motor vehicles. Power is transmitted in a smoother and more efficient manner by splitting torque into two or more torque paths. A continuously variable transmission is provided with a ball variator assembly having an array of balls, a planetary gearset coupled thereto and an arrangement of rotatable shafts with multiple gears and clutches that extend the ratio range of the variator. In some embodiments, a locking clutch is operably coupled to the planetary gearset to selectively couple two of the elements of the planetary gearset during operation. Engagement of the locking clutch corresponds to a fixed ratio operating mode. Disengagement of the locking clutch corresponds to a variable ratio operating mode.

PLANETARY POWERTRAIN CONFIGURATIONS WITH A BALL VARIATOR CONTINUOUSLY VARIABLE TRANSMISSION USED AS A POWERSPLIT

RELATED APPLICATIONS

The present application claims the benefit of U.S. Provisional Application No. 62/338,921 filed on May 19, 2016, U.S. Provisional Application No 62/365,703 filed on July 22, 2016, and U.S. Provisional Application No 62/457,339 filed on February 10, 2017, which are incorporated herein by reference in its entirety.

BACKGROUND

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.

SUMMARY

Provided herein is a continuously variable transmission having: a first rotatable shaft operably coupleable to a source of rotational power; a second rotatable shaft coaxial with the first rotatable shaft, the first rotatable shaft and the second rotatable shaft forming a main axis; a third rotatable shaft aligned parallel to the main axis, the third rotatable shaft forming a counter axis; a variator assembly having a first traction ring assembly and a second traction ring assembly in contact with a plurality of balls, wherein each ball of the plurality of balls has a tiltable axis of rotation, the variator assembly is coaxial with the main axis, the first traction ring assembly operably coupled to the second rotatable shaft; a first planetary gearset having: a first sun gear operably coupled to the second rotatable shaft, a first planet carrier operably coupled to the first rotatable shaft, and a first ring gear coupled to the second traction ring assembly; a chain coupling configured to couple to the second rotatable shaft and the third rotatable shaft; a first-and-third mode clutch coaxial with, and coupled to, the third rotatable shaft; a second-and-fourth mode clutch coaxial with, and coupled to, the third rotatable shaft; a first gear set operably

coupled to the first-and-third mode clutch; a second gear set operably coupled to the second-and-fourth mode clutch; a third gear set operably coupled to the first-and-third mode clutch; a fourth gear set operably coupled to the second-and-fourth mode clutch; a first synchronizer clutch operably coupled to the first gear set; a second synchronizer clutch operably coupled the second gear set; a third synchronizer clutch operably coupled to third gear set; a fourth synchronizer clutch operably coupled to fourth gear set; and a second planetary gear set, coaxial to a fourth rotatable shaft, having: a second ring gear, a second planet carrier, and a second sun gear operably coupled to, and coaxial with, the first synchronizer clutch, the second synchronizer clutch, the third synchronizer clutch, and the fourth synchronizer clutch, wherein the second planet carrier is operably coupled to ground and the second ring gear is configured to couple to transmit an output power.

Provided herein is a continuously variable transmission having: a first rotatable shaft operably coupleable to a source of rotational power; a second rotatable shaft coaxial with the first rotatable shaft, the first rotatable shaft and the second rotatable shaft forming a main axis; a third rotatable shaft aligned parallel to the main axis, the third rotatable shaft forming a counter axis; a variator assembly having a first traction ring assembly and a second traction ring assembly in contact with a plurality of balls, wherein each ball of the plurality of balls has a tiltable axis of rotation, the variator assembly is coaxial with the main axis, the first traction ring assembly operably coupled to the second rotatable shaft; a first planetary gearset having: a first sun gear operably coupled to the second rotatable shaft; a first planet carrier operably coupled to the first rotatable shaft, and a first ring gear coupled to the second traction ring assembly, a chain coupling configured to couple to the second rotatable shaft and the third rotatable shaft; a first mode clutch coaxial with, and coupled to, the third rotatable shaft; a second-and-reverse mode clutch coaxial with, and coupled to, the third rotatable shaft; a first gear set operably coupled to the first mode clutch; a second gear set operably coupled to the second-and-reverse mode clutch; a first synchronizer clutch operably coupled to the first gear set; a second synchronizer clutch operably coupled the second gear set; and a second planetary gear set, coaxial to a fourth rotatable shaft, having: a

second ring gear, a second planet carrier, and a second sun gear operably coupled to, and coaxial with, the first synchronizer clutch and the second synchronizer clutch, wherein the second planet carrier is operably coupled to ground and the second ring gear is configured to couple to transmit an output power.

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 powersplit variator.

Figure 5 is a schematic diagram of a powersplit variator having a locking clutch.

Figure 6 is a schematic diagram of another powersplit variator having a locking clutch.

Figure 7 is a schematic diagram of yet another powersplit variator having a locking clutch.

Figure 8 is a schematic diagram of a variator having a locking clutch coupled between a first traction ring assembly and a second traction ring assembly.

Figure 9 is a schematic diagram of a planetary powersplit continuously variable transmission configured for a front-wheel drive application.

Figure 10 is a table depicting operating modes of the continuously variable transmission of Figure 9.

Figure 11 is a schematic diagram of yet another planetary powersplit continuously variable transmission configured for a front-wheel drive application.

Figure 12 is a table depicting operating modes of the continuously variable transmission depicted in Figure 11.

Figure 13 is a schematic diagram of yet another planetary powersplit continuously variable transmission configured for a front-wheel drive application.

Figure 14 is a table depicting operating modes of the continuously variable transmission depicted in Figure 13.

Figure 15 is a schematic diagram of yet another planetary powersplit continuously variable transmission configured for a front-wheel drive application.

Figure 16 is a table depicting operating modes of the continuously variable transmission depicted in Figure 15.

Figure 17 is a schematic diagram of yet another planetary powersplit continuously variable transmission configured for a front-wheel drive application.

Figure 18 is a table depicting operating modes of the continuously variable transmission depicted in Figure 17

Figure 19 is a schematic diagram of a powersplit variator having a stepped planet planetary gear set.

Figure 20 is a schematic diagram of a powersplit variator having a geared differential.

Figure 21 is a schematic diagram of a powersplit variator having dual sun planetary gear set.

Figure 22 is a schematic diagram of a planetary powersplit variator having a number of couplings for transmitting power out of the variator.

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 includes several novel features, no single one of which is solely responsible for its desirable attributes or which is essential to practicing the embodiments 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, comprises a number of balls (planets, spheres) 1, depending on the application, two 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 fixed from rotation while the second carrier member 7 is configured to rotate with respect to the first carrier member, and vice versa. In one embodiment, 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, 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 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 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 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 one embodiment, a control system coordinates the use of a skew angle to generate forces between certain contacting components in the variator that will tilt the planet axis of rotation. 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 are typically 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 herein, "creep" or "slip" is the discrete local motion of a body relative to another and is exemplified by the relative velocities of rolling contact components such as the mechanism described herein. "Creep" is characterized by the slowing of the output because the transmitted force is stretching the fluid film in the direction of rolling. As used herein, the term "ratio droop" refers to the shift of the tilt angle of the ball axis of rotation (sometimes referred to as the ratio angle or gamma angle) due to a compliance of an

associated control linkage in proportion to a control force that is in proportion to transmitted torque, wherein the compliance of the control linkage corresponds to a change in the skew angle of the ball axis of rotation. As used herein, the term "load droop" refers to any operating event that reduces the ratio of output speed to input speed as transmitted torque increases.

Typically, synchronizer mechanisms (referred to herein as "synchronizer clutch") used in power transmissions include a dog clutch integrated with a speed-matching device such as a cone-clutch. During operation of the transmission, if the dog teeth of the dog clutch make contact with a gear, and the two parts are spinning at different speeds, the teeth will fail to engage and a loud grinding sound will be heard as they clatter together. For this reason, a synchronizer mechanism or synchronizer clutch is used, which consists of a cone clutch. Before the teeth engage, the cone clutch engages first, which brings the two rotating elements to the same speed using friction. Until synchronization occurs, the teeth are prevented from making contact. It should be appreciated that the exact design of the synchronizer clutch is within a designer's choice for satisfying packaging and performance requirements. A synchronizer clutch is optionally configured to be a two position clutch having an engaged position and a neutral (or free) position. A synchronizer clutch is optionally configured to be a three position clutch having a first engaged position, a second engaged position, and a neutral position. Embodiments disclosed herein use synchronizer clutches to enable the pre-selection of gear sets by a control system (not shown) for smooth transition between operating modes of the transmission. It should be appreciated that the powertrain configurations disclosed herein are optionally configured with other types of selectable torque transmitting devices including, and not limited to, wet clutches, dry clutches, dog clutches, and electromagnetic clutches, among others.

Referring now to FIG. 4, in some embodiments, a powersplit variator 10 includes a first rotatable shaft 11 adapted to receive power from a source of rotational power (not shown). The powersplit variator 10 includes a second rotatable shaft 12 adapted to transmit a rotational power out of the powersplit variator 10. For example, the second rotatable shaft 12 is adapted to couple to

a multiple speed gear box (not shown) to provide multiple modes of operation. In some embodiments, the second rotatable shaft 12 is adapted to couple to a fixed ratio automatic transmission such as well-known multiple speed automatic transmissions or simplified versions thereof utilizing alternative friction plate clutches. It should be appreciated that other embodiments of powersplit variators are optionally configured to couple to the power transmission devices disclosed herein. In some embodiments, the powersplit variator 10 includes a variator 13. The variator 13 is optionally configured to be a variator similar to the variator depicted in FIGS. 1-3. The variator 13 is provided with a first traction ring assembly 15 and a second traction ring assembly 14. In some embodiments, the powersplit variator 10 includes a planetary gear set 16 having a ring gear 17, a planet carrier 18, and a sun gear 19. The ring gear 17 is operably coupled to the second traction ring assembly 14. The sun gear 19 is operably coupled to the second rotatable shaft 12. In some embodiments, the second rotatable shaft 12 is coupled to the first traction ring assembly 15. It should be noted that in some embodiments, the first rotatable shaft 11 is adapted to transmit power out of the powersplit variator 10 and the second rotatable shaft 12 is adapted to operably couple to a source of rotational power.

Referring now to FIG. 5, in some embodiments; a powersplit variator 60 includes a first rotatable shaft 61 adapted to receive power from a source of rotational power (not shown). The powersplit variator 60 includes a second rotatable shaft 62 adapted to transmit a rotational power out of the powersplit variator 60. For example, the second rotatable shaft 62 is adapted to couple to a multiple speed gear box (not shown) to provide multiple modes of operation. In some embodiments, the second rotatable shaft 62 is adapted to couple to a fixed ratio automatic transmission such as the General Motors 4L60/4L80 transmission, the Ford Motor Company 4R70, and other well-known multiple speed automatic transmissions or simplified versions thereof utilizing alternative friction plate clutches. It should be appreciated that embodiments of powersplit variators disclosed here are optionally configured to couple to any power transmission device. In some embodiments, the powersplit variator 60 includes a variator 63. The variator 63 is optionally configured to be a variator similar to the variator depicted in FIGS. 1-3. The variator 63 is provided with a

first traction ring assembly 65 and a second traction ring assembly 64. In some embodiments, the powersplit variator 60 includes a planetary gear set 66 having a ring gear 67, a planet carrier 68, and a sun gear 69. The ring gear 67 is operably coupled to the second traction ring assembly 64. The sun gear 69 is operably coupled to the second rotatable shaft 62. In some embodiments, the second rotatable shaft 62 is coupled to the first traction ring assembly 65. In some embodiments, the powersplit variator 60 includes a locking clutch 70 operably coupled to the ring gear 67 and the planet carrier 68. It should be noted that in some embodiments, the first rotatable shaft 61 is adapted to transmit power out of the powersplit variator 60 and the second rotatable shaft 62 is adapted to operably couple to a source of rotational power.

Referring now to FIG. 6, in some embodiments; a powersplit variator 75 includes a first rotatable shaft 76 adapted to receive power from a source of rotational power (not shown). The powersplit variator 75 includes a second rotatable shaft 77 configured to transmit an output power from the powersplit variator 75. The powersplit variator 75 includes a variator 78 having a first traction ring assembly 80 and a second traction ring assembly 79. The powersplit variator 75 includes a planetary gear set 81 having a ring gear 82, a planet carrier 83, and a sun gear 84. In some embodiments, the ring gear 82 is operably coupled to the second traction ring assembly 79. The sun gear 84 is coupled to the second rotatable shaft 77. The first traction ring assembly 80 is coupled to the second rotatable shaft 77. In some embodiments, the powersplit variator 75 is provided with a locking clutch 85 coupled to the planet carrier 83 and the sun gear 84. It should be noted that in some embodiments, the first rotatable shaft 76 is adapted to transmit power out of the powersplit variator 75 and the second rotatable shaft 77 is adapted to operably couple to a source of rotational power.

Referring now to FIG. 7, in some embodiments; a powersplit variator 90 includes a first rotatable shaft 91 adapted to receive power from a source of rotational power (not shown). The powersplit variator 90 includes a second rotatable shaft 92 configured to transmit an output power from the powersplit variator 90. The powersplit variator 90 includes a variator 93 having a first traction ring assembly 95 and a second traction ring assembly 94. The

powersplit variator 90 includes a planetary gear set 96 having a ring gear 97, a planet carrier 98, and a sun gear 99. In some embodiments, the ring gear 97 is operably coupled to the second traction ring assembly 94. The sun gear 99 is coupled to the second rotatable shaft 92. The first traction ring assembly 95 is coupled to the second rotatable shaft 92. In some embodiments, the powersplit variator 90 is provided with a locking clutch 100 coupled to the ring gear 97 and the sun gear 99. It should be noted that in some embodiments, the first rotatable shaft 91 is adapted to transmit power out of the powersplit variator 90 and the second rotatable shaft 92 is adapted to operably couple to a source of rotational power.

Referring now to FIG. 8, in some embodiments, a variator 160 is provided with a first traction ring assembly 161 and a second traction ring assembly 162 in contact with a plurality of balls. The variator 160 is similar to the variator depicted in FIGS. 1-3. The first traction ring assembly 161 is coupled to a first rotatable shaft 163. In some embodiments, the first rotatable shaft 163 is adapted to operably couple to a source of rotational power. In other embodiments, the first rotatable shaft 163 is adapted to transmit a power out of the variator 160. The second traction ring assembly 162 is operably coupled to a second rotatable shaft 164. In some embodiments, the second rotatable shaft 164 is adapted to transmit a power out of the variator 160. In other embodiments, the second rotatable shaft 164 is adapted to operably couple to a source of rotational power. The variator 160 is optionally provided with a locking clutch 165 coupled to the first traction ring assembly 161 and the second rotatable shaft 164. The locking clutch 165 is configured to selectively engage the first traction ring assembly 161 and the second rotatable shaft 164 to thereby transmit power from the first rotatable shaft 163 to the second rotatable shaft 164.

It should be appreciated that the locking clutch 25, the locking clutch 56, the locking clutch 70, the locking clutch 85, and the locking clutch 100 disclosed herein are optionally configured as wet clutch, dry clutches, synchronizer clutches, one-way clutches, or mechanical diodes. In some embodiments, the continuously variable transmissions disclosed herein are optionally configured to include powersplit variator devices such as the devices

disclosed in FIGS. 4-8, and described with related control methods in U.S. Patent Application No. 62/333,632, which is hereby incorporated by reference.

Referring now to FIG. 9, in some embodiments; a continuously variable transmission (CVT) 200 includes a powersplit variator 201 having a first rotatable shaft 202 and a second rotatable shaft 203. In some embodiments, the powersplit variator 201 is configured such as the variators described in FIGS. 1-8. The first rotatable shaft 202 is configured to operably couple to a source of rotational power (not shown). The second rotatable shaft 203 is coupled to a chain coupling 204. The chain coupling 204 couples to a third rotatable shaft 205. The third rotatable shaft 205 is arranged parallel to the second rotation shaft 203. In some embodiments, the chain coupling 204 includes a number of sprockets engaged with a chain. In other embodiments, the chain coupling 204 is optionally configured as a belt and pulley coupling, a gear set, or other device for transmitting rotational power between parallel shafts. In some embodiments, the third rotatable shaft 205 is configured to operably couple to a first-and-third mode clutch 206 and a second-and-fourth mode clutch 207. The first-and-third mode clutch 206 and the second-and-fourth mode clutch 207 are arranged coaxial with the third rotatable shaft 205. The first-and-third mode clutch 206 is operably coupled to a first gear set 208. The first gear set 208 is configured to couple to a first synchronizer clutch 209. The second-and-fourth mode clutch 207 is operably coupled to a second gear set 210. The second gear set 210 is operably coupled to a second synchronizer clutch 211. The first-and-third mode clutch 206 is operably coupled to a third gear set 212. The third gear set 212 is operably coupled to a third synchronizer clutch 213. The second-and-fourth mode clutch 207 is operably coupled to a fourth gear set 214. The fourth clutch gear set 214 is operably coupled to a fourth synchronizer clutch 215. The first-and-third mode clutch 206 is operably coupled to a reverse gear set 216. The reverse gear set 216 is operably coupled to a reverse synchronizer clutch 217. The first synchronizer clutch 209, the second synchronizer clutch 211, the third synchronizer clutch 213, the fourth synchronizer clutch 215, and the reverse synchronizer clutch 217 are arranged coaxial with a fourth rotatable shaft 218. The fourth rotatable shaft 218 is arranged parallel to the third rotatable shaft

205. In some embodiments, the fourth rotatable shaft 218 is configured to transmit an output power. In some embodiments, a planetary gear set 219 is arranged coaxially with the fourth rotatable shaft 218. The planetary gear set 219 includes a sun gear 220, a planet carrier 221, and a ring gear 222. The sun gear 220 is operably coupled to the first synchronizer clutch 209, the second synchronizer clutch 211, the third synchronizer clutch 213, the fourth synchronizer clutch 215, and the reverse synchronizer clutch 217. The planet carrier 221 is operably coupled to a non-rotatable member of the transmission, such as a housing (not shown). The ring gear 222 is operably coupled to the fourth rotatable shaft 218 to facilitate transmission of output power.

Referring now to FIG. 10, during operation of the CVT 200, multiple modes of operation are achieved through engagement of the various clutching devices to provide modes corresponding to overlapping ranges of speed and torque. Typically, the first mode of operation corresponds to a launch mode of a vehicle from a stop. The subsequent modes engaged correspond to higher speed ranges. Likewise, the reverse mode of operation corresponds to a reverse direction of a vehicle equipped with the CVT 200. The table depicted in FIG. 10, lists the modes of operation for the CVT 200 and indicates with an "x" the corresponding clutch engagement. For mode 1 operation, the first-and-third mode clutch 206 and the first synchronizer clutch 209 are engaged. For mode 2 operation, the second-and-fourth mode clutch 207 and the second synchronizer clutch 211 are engaged. For mode 3 operation, the first-and-third mode clutch 206 and the third synchronizer clutch 213 are engaged. For mode 4 operation, the second-and-fourth mode clutch 206 and the fourth synchronizer clutch 215 are engaged. For reverse mode operation, the first-and-third mode clutch 206 and the reverse synchronizer clutch 217 are engaged. In some embodiments, the powersplit variator 201 is provided with a locking clutch such as the powersplit variators depicted in FIGS. 5-8. In these embodiments, the locking clutch is optionally configured to selectively engage during operation to provide a fixed ratio operating mode as an optional gear in any of the four modes of operation depicted in FIG. 10. During fixed ratio operating modes, power is transmitting through fixed gear ratios and the variator operates at a 1:1 speed ratio without transmitting any power. For

example, engagement of the locking clutch in mode 1 provides a fixed ratio for vehicle launch from a stop. The locking clutch can be disengaged when a desired vehicle speed is reach and the vehicle continues to operate in mode 1 with power transmitted through the variator. The locking clutch can be engaged during mode 2, mode 3, mode 4, or reverse operation to transmit power through fixed gear ratios and effectively bypass the variator.

Referring now to FIG. 11, in some embodiments; a continuously variable transmission (CVT) 475 includes a powersplit variator 476 having a first rotatable shaft 477 and a second rotatable shaft 478. In some embodiments, the powersplit variator 476 is configured such as the variators described in FIGS. 1-8. The first rotatable shaft 477 is configured to operably couple to a source of rotational power (not shown). The second rotatable shaft 478 is coupled to a chain coupling 479. The chain coupling 479 couples to a third rotatable shaft 480. The third rotatable shaft 480 is arranged parallel to the second rotatable shaft 478. In some embodiments, the chain coupling 479 includes a number of sprockets engaged with a chain. In other embodiments, the chain coupling 479 is optionally configured as a belt and pulley coupling, a gear set, or other device for transmitting rotational power between parallel shafts. In some embodiments, the third rotatable shaft 480 is configured to operably couple to a first mode clutch 481 and a second-and-reverse mode clutch 482. The first mode clutch 481 and the second-and-reverse mode clutch 482 are arranged coaxial with the third rotatable shaft 480. The first mode clutch 481 is operably coupled to a first gear set 483. The first gear set 483 is configured to couple to a first synchronizer clutch 484. The second-and-reverse mode clutch 482 is operably coupled to a second gear set 485. The second gear set 485 is operably coupled to a second synchronizer clutch 486. The first mode clutch 481 is operably coupled to a reverse gear set 487. The reverse gear set 487 is operably coupled to a reverse synchronizer clutch 488. The first synchronizer clutch 484, the second synchronizer clutch 486, and the reverse synchronizer clutch 488 are arranged coaxial with a fourth rotatable shaft 489. The fourth rotatable shaft 489 is arranged parallel to the third rotatable shaft 480. In some embodiments, the fourth rotatable shaft 489 is configured to transmit an output power. In some embodiments, a planetary

gear set 490 is arranged coaxially with the fourth rotatable shaft 489. The planetary gear set 490 includes a sun gear 491, a planet carrier 492, and a ring gear 493. The sun gear 491 is operably coupled to the first synchronizer clutch 484, the second synchronizer clutch 486, and the reverse synchronizer clutch 488. The planet carrier 492 is operably coupled to a non-rotatable member of the transmission, such as a housing (not shown). The ring gear 493 is operably coupled to the fourth rotatable shaft 489 to facilitate transmission of output power.

Referring now to FIG. 12, during operation of the CVT 475, multiple modes of operation are achieved through engagement of the various clutching devices to provide modes corresponding to overlapping ranges of speed and torque. Typically, the first mode of operation corresponds to a launch mode of a vehicle from a stop. The subsequent modes engaged correspond to higher speed ranges. Likewise, the reverse mode of operation corresponds to a reverse direction of a vehicle equipped with the CVT 475. The table depicted in FIG. 12, lists the modes of operation for the CVT 475 and indicates with an "x" the corresponding clutch engagement. For mode 1 operation, the first mode clutch 481 and the first synchronizer clutch 484 are engaged. For mode 2 operation, the second-and-reverse mode clutch 482 and the second synchronizer clutch 484 are engaged. For reverse mode operation, the second-and-reverse mode clutch 482 and the reverse synchronizer clutch 488 are engaged. In some embodiments, the powersplit variator 476 is provided with a locking clutch such as the powersplit variators depicted in FIGS. 5-8. In these embodiments, the locking clutch is optionally configured to selectively engage during operation to provide a fixed ratio operating mode as an optional gear in any of the three modes of operation depicted in FIG. 12. During fixed ratio operating modes, power is transmitting through fixed gear ratios and the variator operates at a 1:1 speed ratio without transmitting any power. For example, engagement of the locking clutch in mode 1 provides a fixed ratio for vehicle launch from a stop. The locking clutch can be disengaged when a desired vehicle speed is reach and the vehicle continues to operate in mode 1 with power transmitted through the variator. The locking clutch can be

engaged during mode 2, or reverse operation to transmit power through fixed gear ratios and effectively bypass the variator.

Referring now to FIG. 13, in some embodiments; a continuously variable transmission (CVT) 500 includes a powersplit variator 501 having a first rotatable shaft 502 and a second rotatable shaft 503. In some embodiments, the powersplit variator 501 is configured such as the variators described in FIGS. 1-8. The first rotatable shaft 502 is configured to operably couple to a source of rotational power (not shown). The second rotatable shaft 503 is coupled to a chain coupling 504. The chain coupling 504 couples to a third rotatable shaft 505. The third rotatable shaft 505 is arranged parallel to the second rotatable shaft 503. In some embodiments, the chain coupling 504 includes a number of sprockets engaged with a chain. In other embodiments, the chain coupling 504 is optionally configured as a belt and pulley coupling, a gear set, or other device for transmitting rotational power between parallel shafts. In some embodiments, the third rotatable shaft 505 is configured to operably couple to a first-and-third mode clutch 506 and a second-and-reverse mode clutch 507. The first-and-third mode clutch 506 and the second-and-reverse mode clutch 507 are arranged coaxial with the third rotatable shaft 516. The first-and-third mode clutch 506 is operably coupled to a first gear set 508. The first gear set 508 is configured to couple to a first synchronizer clutch 509. The second-and-reverse mode clutch 507 is operably coupled to a second gear set 510. The second gear set 510 is operably coupled to a second synchronizer clutch 511. The first-and-third mode clutch 506 is operably coupled to a third gear set 512. The third gear set 512 is operably coupled to a third synchronizer clutch 513. The second-and-reverse mode clutch 507 is operably coupled to a reverse gear set 514. The reverse gear set 514 is operably coupled to a reverse synchronizer clutch 515. The first synchronizer clutch 509, the second synchronizer clutch 511, the third synchronizer clutch 513, and the reverse synchronizer clutch 515 are arranged coaxial with a fourth rotatable shaft 516. The fourth rotatable shaft 516 is arranged parallel to the third rotatable shaft 505. In some embodiments, the fourth rotatable shaft 516 is configured to transmit an output power. In some embodiments, a planetary gear set 517 is arranged coaxially with the fourth rotatable shaft 516. The

planetary gear set 517 includes a sun gear 518, a planet carrier 519, and a ring gear 520. The sun gear 518 is operably coupled to the first synchronizer clutch 509, the second synchronizer clutch 511, the third synchronizer clutch 513, and the reverse synchronizer clutch 515. The planet carrier 518 is operably coupled to a non-rotatable member of the transmission, such as a housing (not shown). The ring gear 520 is operably coupled to the fourth rotatable shaft 516 to facilitate transmission of output power.

Referring now to FIG. 14, during operation of the CVT 500, multiple modes of operation are achieved through engagement of the various clutching devices to provide modes corresponding to overlapping ranges of speed and torque. Typically, the first mode of operation corresponds to a launch mode of a vehicle from a stop. The subsequent modes engaged correspond to higher speed ranges. Likewise, the reverse mode of operation corresponds to a reverse direction of a vehicle equipped with the CVT 500. The table depicted in FIG. 14, lists the modes of operation for the CVT 500 and indicates with an "x" the corresponding clutch engagement. For mode 1 operation, the first-and-third mode clutch 506 and the first synchronizer clutch 509 are engaged. For mode 2 operation, the second-and-reverse mode clutch 507 and the second synchronizer clutch 511 are engaged. For mode 3 operation, the first-and-third mode clutch 506 and the third synchronizer clutch 513 are engaged. For reverse mode operation, the second-and-reverse mode clutch 507 and the reverse synchronizer clutch 515 are engaged. In some embodiments, the powersplit variator 501 is provided with a locking clutch such as the powersplit variators depicted in FIGS. 5-8. In these embodiments, the locking clutch is optionally configured to selectively engage during operation to provide a fixed ratio operating mode as an optional gear in any of the three modes of operation depicted in FIG. 14. During fixed ratio operating modes, power is transmitting through fixed gear ratios and the variator operates at a 1:1 speed ratio without transmitting any power. For example, engagement of the locking clutch in mode 1 provides a fixed ratio for vehicle launch from a stop. The locking clutch can be disengaged when a desired vehicle speed is reach and the vehicle continues to operate in mode 1 with power transmitted through the variator. The locking clutch can be engaged during mode 2, mode 3, or reverse

operation to transmit power through fixed gear ratios and effectively bypass the variator.

Referring now to FIG. 15, in some embodiments, a continuously variable transmission (CVT) 600 includes a variator 601 having a first traction ring assembly 602 and a second traction ring assembly 603. In some embodiments, the first traction ring assembly 602 is coupled to a first rotatable shaft 604. In some embodiments, the variator 601 is configured such as the variators described in FIGS. 1-8. The first rotatable shaft 604 is configured to operably couple to a source of rotational power (not shown). The second traction ring assembly 603 is coupled to a chain coupling 605. The chain coupling 605 couples to a second rotatable shaft 606. The second rotatable shaft 606 is arranged parallel to the first rotatable shaft 604. In some embodiments, the chain coupling 605 includes a number of sprockets engaged with a chain. In other embodiments, the chain coupling 605 is optionally configured as a belt and pulley coupling, a gear set, or other device for transmitting rotational power between parallel shafts. In some embodiments, the second rotatable shaft 606 is configured to operably couple to a first mode clutch 607 and a second-and-reverse mode clutch 608. The first mode clutch 607 and the second-and-reverse mode clutch 608 are arranged coaxial with the second rotatable shaft 606. The first mode clutch 607 is operably coupled to a first gear set 609. The second-and-reverse mode clutch 608 is operably coupled to a second gear set 610. The second gear set 610 is operably coupled to a second synchronizer clutch 611. The second-and-reverse mode clutch 608 is operably coupled to a reverse gear set 612. The reverse gear set 612 is operably coupled to a reverse synchronizer clutch 613. The first gear set 609, the second synchronizer clutch 611, and the reverse synchronizer clutch 613 are arranged coaxial with a third rotatable shaft 614. The third rotatable shaft 614 is arranged parallel to the second rotatable shaft 606. In some embodiments, the third rotatable shaft 614 is configured to transmit an output power. In some embodiments, a planetary gear set 615 is arranged coaxially with the third rotatable shaft 614. The planetary gear set 615 includes a sun gear 616, a planet carrier 617, and a ring gear 618. The sun gear 616 is operably coupled to the first gear set 609, the second synchronizer clutch 611,

and the reverse synchronizer clutch 613. The planet carrier 617 is operably coupled to a non-rotatable member of the transmission, such as a housing (not shown). The ring gear 618 is operably coupled to the third rotatable shaft 614 to facilitate transmission of output power.

Referring now to FIG. 16, during operation of the CVT 600, multiple modes of operation are achieved through engagement of the various clutching devices to provide modes corresponding to overlapping ranges of speed and torque. Typically, the first mode of operation corresponds to a launch mode of a vehicle from a stop. The subsequent modes engaged correspond to higher speed ranges. Likewise, the reverse mode of operation corresponds to a reverse direction of a vehicle equipped with the CVT 600. The table depicted in FIG. 16, lists the modes of operation for the CVT 600 and indicates with an "x" the corresponding clutch engagement. For mode 1 operation, the first mode clutch 607 is engaged. For mode 2 operation, the second-and-reverse mode clutch 608 and the second synchronizer clutch 611 are engaged. For reverse mode operation, the second-and-reverse mode clutch 608 and the reverse synchronizer clutch 613 are engaged. In some embodiments, the variator 600 is provided with a locking clutch such as the powersplit variators depicted in FIGS. 5-8. In these embodiments, the locking clutch is optionally configured to selectively engage during operation to provide a fixed ratio operating mode as an optional gear in any of the three modes of operation depicted in FIG. 16. During fixed ratio operating modes, power is transmitting through fixed gear ratios and the variator operates at a 1:1 speed ratio without transmitting any power. For example, engagement of the locking clutch in mode 1 provides a fixed ratio for vehicle launch from a stop. The locking clutch can be disengaged when a desired vehicle speed is reach and the vehicle continues to operate in mode 1 with power transmitted through the variator. The locking clutch can be engaged during mode 2, or reverse operation to transmit power through fixed gear ratios and effectively bypass the variator.

Referring now to FIG. 17, in some embodiments; a continuously variable transmission (CVT) 625 includes a powersplit variator 626 having a first rotatable shaft 627 and a second rotatable shaft 628. In some embodiments, the powersplit variator 626 is configured such as the variators described in

FIGS. 1-8. The first rotatable shaft 627 is configured to operably couple to a source of rotational power (not shown). The second rotatable shaft 628 is coupled to a chain coupling 629. The chain coupling 629 couples to a third rotatable shaft 630. The third rotatable shaft 630 is arranged parallel to the second rotatable shaft 628. In some embodiments, the chain coupling 629 includes a number of sprockets engaged with a chain. In other embodiments, the chain coupling 629 is optionally configured as a belt and pulley coupling, a gear set, or other device for transmitting rotational power between parallel shafts. In some embodiments, the third rotatable shaft 630 is configured to operably couple to a first mode clutch 631 and a second-and-reverse mode clutch 632. The first mode clutch 631 and the second-and-reverse mode clutch 632 are arranged coaxial with the third rotatable shaft 630. The first mode clutch 631 is operably coupled to a first gear set 633. The second-and-reverse mode clutch 632 is operably coupled to a second gear set 634. The second gear set 634 is operably coupled to a second synchronizer clutch 635. The second-and-reverse mode clutch 632 is operably coupled to a reverse gear set 636. The reverse gear set 636 is operably coupled to a reverse synchronizer clutch 637. The first gear set 633, the second synchronizer clutch 635, and the reverse synchronizer clutch 637 are arranged coaxial with a fourth rotatable shaft 638. The fourth rotatable shaft 638 is arranged parallel to the third rotatable shaft 630. In some embodiments, the fourth rotatable shaft 638 is configured to transmit an output power. In some embodiments, a planetary gear set 639 is arranged coaxially with the fourth rotatable shaft 638. The planetary gear set 639 includes a sun gear 640 a planet carrier 641, and a ring gear 642. The sun gear 640 is operably coupled to the first gear set 633, the second synchronizer clutch 635, and the reverse synchronizer clutch 637. The planet carrier 640 is operably coupled to a non-rotatable member of the transmission, such as a housing (not shown). The ring gear 642 is operably coupled to the fourth rotatable shaft 638 to facilitate transmission of output power.

Referring now to FIG. 18, during operation of the CVT 625, multiple modes of operation are achieved through engagement of the various clutching devices to provide modes corresponding to overlapping ranges of speed and

torque. Typically, the first mode of operation corresponds to a launch mode of a vehicle from a stop. The subsequent modes engaged correspond to higher speed ranges. Likewise, the reverse mode of operation corresponds to a reverse direction of a vehicle equipped with the CVT 625. The table depicted in FIG. 18, lists the modes of operation for the CVT 625 and indicates with an "x" the corresponding clutch engagement. For mode 1 operation, the first mode clutch 631 is engaged. For mode 2 operation, the second-and-reverse mode clutch 632 and the second synchronizer clutch 635 are engaged. For reverse mode operation, the second-and-reverse mode clutch 632 and the reverse synchronizer clutch 637 are engaged. In some embodiments, the powersplit variator 626 is provided with a locking clutch such as the powersplit variators depicted in FIGS. 5-8. In these embodiments, the locking clutch is optionally configured to selectively engage during operation to provide a fixed ratio operating mode as an optional gear in any of the three modes of operation depicted in FIG. 18. During fixed ratio operating modes, power is transmitting through fixed gear ratios and the variator operates at a 1:1 speed ratio without transmitting any power. For example, engagement of the locking clutch in mode 1 provides a fixed ratio for vehicle launch from a stop. The locking clutch can be disengaged when a desired vehicle speed is reach and the vehicle continues to operate in mode 1 with power transmitted through the variator. The locking clutch can be engaged during mode 2, or reverse operation to transmit power through fixed gear ratios and effectively bypass the variator. It should be appreciated that the CVTs described herein depicted multiple modes of operation, and that it is within a designer's means to configure the CVTs described herein to have two, three, four, five, or more modes to suit a particular application.

Turning now to FIGS. 19-22, embodiments of powersplit variators that are implementable in the continuously variable transmissions disclosed herein will be described. It should be appreciated that it is within a designer's means to use a variety of powersplit variator configurations with the continuously variable transmission configurations described to achieve desired operating and packaging parameters.

Referring to FIG. 19, in some embodiments, a powersplit variator 700 includes a first rotatable shaft 701 adapted to receive power from a source of rotational power (not shown). The powersplit variator 700 includes a second rotatable shaft 702 adapted to transmit a rotational power out of the powersplit variator 700. For example, the second rotatable shaft 702 is adapted to couple to a multiple speed gear box (not shown) to provide multiple modes of operation. In some embodiments, the second rotatable shaft 702 is adapted to couple to a fixed ratio automatic transmission such as well-known multiple speed automatic transmissions or simplified versions thereof utilizing alternative friction plate clutches. In some embodiments, the powersplit variator 700 includes a variator 703. The variator 703 is optionally configured to be a variator similar to the variator depicted in FIGS. 1-3. The variator 703 is provided with a first traction ring assembly 705 and a second traction ring assembly 704. In some embodiments, the powersplit variator 700 includes a planetary gear set 706 having a sun gear 707, a planet carrier 708 configured to support a number of stepped planet gears 709, and a ring gear 710. The ring gear 707 is operably coupled to the second traction ring assembly 704. The sun gear 707 is operably coupled to the second rotatable shaft 702. In some embodiments, the second rotatable shaft 702 is coupled to the first traction ring assembly 705. It should be noted that in some embodiments, the first rotatable shaft 701 is adapted to transmit power out of the powersplit variator 700 and the second rotatable shaft 702 is adapted to operably couple to a source of rotational power.

Referring to FIG. 20, in some embodiments, a powersplit variator 725 includes a first rotatable shaft 726 adapted to receive power from a source of rotational power (not shown). The powersplit variator 725 includes a second rotatable shaft 727 adapted to transmit a rotational power out of the powersplit variator 725. For example, the second rotatable shaft 727 is adapted to couple to a multiple speed gear box (not shown) to provide multiple modes of operation. In some embodiments, the powersplit variator 725 includes a variator 728. The variator 728 is optionally configured to be a variator similar to the variator depicted in FIGS. 1-3. The variator 728 is provided with a first traction ring assembly 730 and a second traction ring assembly 729. In some

embodiments, the powersplit variator 725 includes a differential gear set 706 having a planet carrier 731 operably coupled to the first rotatable shaft 726. The planet carrier 731 is configured to support a number of bevel gears 734 of the well-known conical type typically used in differential gear sets. The bevel gears 734 are coupled to a ring gear 733 and a sun gear 735. The ring gear 733 is coupled to the second traction ring assembly 729. The sun gear 735 is coupled to the second rotatable shaft 727. The first traction ring assembly 730 is coupled to the second rotatable shaft 727. It should be noted that in some embodiments, the first rotatable shaft 726 is adapted to transmit power out of the powersplit variator 725 and the second rotatable shaft 727 is adapted to operably couple to a source of rotational power.

Referring now to FIG. 21, in some embodiments, a powersplit variator 745 includes a first rotatable shaft 746 adapted to receive power from a source of rotational power (not shown). The powersplit variator 745 includes a second rotatable shaft 747 adapted to transmit a rotational power out of the powersplit variator 745. For example, the second rotatable shaft 747 is adapted to couple to a multiple speed gear box (not shown) to provide multiple modes of operation. In some embodiments, the powersplit variator 745 includes a variator 748. The variator 748 is optionally configured to be a variator similar to the variator depicted in FIGS. 1-3. The variator 748 is provided with a first traction ring assembly 750 and a second traction ring assembly 749. In some embodiments, the powersplit variator 745 includes a planetary gear set 751 having a planet carrier 752 configured to support a first array of planet gears 753. The first array of planet gears 753 are coupled to a first sun gear 754. The planet carrier 752 is configured to support a second array of planet gears 755. The second array of planet gears 755 are coupled to a second sun gear 756. The second sun gear 756 is operably coupled to the second traction ring assembly 749. The first sun gear 754 is operably coupled to the second rotatable shaft 747. In some embodiments, the second rotatable shaft 747 is coupled to the first traction ring assembly 750. It should be noted that in some embodiments, the first rotatable shaft 746 is adapted to transmit power out of the powersplit variator 745 and the second rotatable shaft 747 is adapted to

operably couple to a source of rotational power. In some embodiments, the second sun gear 756 is configured to provide an optional power output.

Referring now to FIG. 22, in some embodiments, a powersplit variator 760 is provided with a first rotatable shaft 761 adapted to receive power from a source of rotational power. In some embodiments, the first rotatable shaft 761 is operably coupled to a torque converter device, or other common coupling. The powersplit variator 760 is provided with a variator (CVP) 762 aligned coaxially with the first rotatable shaft 761. In some embodiments, the variator 762 is similar to the variator depicted in FIGS. 1-3. The variator 762 includes a first traction ring assembly 763 and a second traction ring assembly 764 in contact with a number of balls. In some embodiments, the powersplit variator 760 includes a planetary gear set 765 aligned coaxially with the first rotatable shaft 761 and the variator 762. The planetary gear set 765 includes a ring gear 766, a planet carrier 767, and a sun gear 768. In some embodiments, the planet carrier 767 is coupled to the first rotatable shaft 761. The ring gear 766 is coupled to the second traction ring assembly 764. In some embodiments, the powersplit variator 760 has a first gear set 769 operably coupled to the first traction ring assembly 763. The first gear set 769 is configured to provide a power output path through a first coupling device 770. In some embodiments, the powersplit variator 760 has a second gear set 771 operably coupled to the sun gear 768 and the first gear set 769. The second gear set 771 is configured to provide a power output path through a second coupling device 772. In some embodiments, the powersplit variator 760 has a third gear set 773 operably coupled to the second traction ring assembly 764. The third gear set 771 is configured to provide a power output path through a third coupling device 774. It should be appreciated that the first coupling device 770, the second coupling device 772, and the third coupling device 773 are optionally configured by a designer to achieve desired performance and packaging of the continuously variable transmission.

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

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 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 practice. It is intended that the following claims define the scope of the preferred embodiments and that methods and structures within the scope of these claims and their equivalents be covered thereby.

WHAT IS CLAIMED IS:

1. A continuously variable transmission comprising:

a first rotatable shaft operably coupleable to a source of rotational power;

a second rotatable shaft coaxial with the first rotatable shaft, the first rotatable shaft and the second rotatable shaft forming a main axis;

a third rotatable shaft aligned parallel to the main axis, the third rotatable shaft forming a counter axis;

a variator assembly having a first traction ring assembly and a second traction ring assembly in contact with a plurality of balls, wherein each ball of the plurality of balls has a tiltable axis of rotation, the variator assembly is coaxial with the main axis, the first traction ring assembly is operably coupled to the second rotatable shaft;

a first planetary gearset comprising:

a first sun gear operably coupled to the second rotatable shaft,

a first planet carrier operably coupled to the first rotatable shaft, and

a first ring gear coupled to the second traction ring assembly;

a chain coupling configured to couple to the second rotatable shaft and the third rotatable shaft;

a first-and-third mode clutch coaxial with, and coupled to, the third rotatable shaft;

a second-and-fourth mode clutch coaxial with, and coupled to, the third rotatable shaft;

a first gear set operably coupled to the first-and-third mode clutch;

a second gear set operably coupled to the second-and-fourth mode clutch;

a third gear set operably coupled to the first-and-third mode clutch;

a fourth gear set operably coupled to the second-and-fourth mode clutch;

a first synchronizer clutch operably coupled to the first gear set;

a second synchronizer clutch operably coupled the second gear set;

a third synchronizer clutch operably coupled to the third gear set;

a fourth synchronizer clutch operably coupled to the fourth gear set; and

a second planetary gear set, coaxial to a fourth rotatable shaft, comprising:

a second ring gear,

a second planet carrier, and

a second sun gear operably coupled to, and coaxial with, the first synchronizer clutch, the second synchronizer clutch, the third synchronizer clutch, and the fourth synchronizer clutch,

wherein the second planet carrier is operably coupled to ground and the second ring gear is configured to couple to transmit an output power.

2. The continuously variable transmission of Claim 1, wherein the second planetary gear set, the fourth rotatable shaft, the first synchronizer clutch, the second synchronizer clutch, the third synchronizer clutch, and the fourth synchronizer clutch are arranged parallel to the third rotatable shaft and arranged parallel to the third rotatable shaft.

3. The continuously variable transmission of Claim 1, further comprising a reverse synchronizer clutch operably coupled to the second sun gear.

4. The continuously variable transmission of Claim 1, further comprising a locking clutch operably coupled to the first planetary gear set, wherein the locking clutch is adapted to selectively engage a fixed ratio mode of operation.

5. A continuously variable transmission comprising:

a first rotatable shaft operably coupleable to a source of rotational power;

a second rotatable shaft coaxial with the first rotatable shaft, the first rotatable shaft and the second rotatable shaft forming a main axis;

a third rotatable shaft aligned parallel to the main axis, the third rotatable shaft forming a counter axis;

a variator assembly having a first traction ring assembly and a second traction ring assembly in contact with a plurality of balls, wherein each ball of the plurality of balls has a tiltable axis of rotation, the variator assembly is coaxial with the main axis, the first traction ring assembly operably coupled to the second rotatable shaft;

a first planetary gearset comprising:

a first sun gear operably coupled to the second rotatable shaft,

a first planet carrier operably coupled to the first rotatable shaft, and

a first ring gear coupled to the second traction ring assembly;

a chain coupling configured to couple to the second rotatable shaft and the third rotatable shaft;

a first mode clutch coaxial with, and coupled to, the third rotatable shaft;

a second-and-reverse mode clutch coaxial with, and coupled to, the third rotatable shaft;

a first gear set operably coupled to the first mode clutch;

a second gear set operably coupled to the second-and-reverse mode clutch;

a first synchronizer clutch operably coupled to the first gear set;

a second synchronizer clutch operably coupled the second gear set; and

a second planetary gear set, coaxial to a fourth rotatable shaft, comprising:

a second ring gear,

a second planet carrier, and

a second sun gear operably coupled to, and coaxial with, the first synchronizer clutch and the second synchronizer clutch, wherein the second planet carrier is operably coupled to ground and the second ring gear is configured to couple to transmit an output power.

6. The continuously variable transmission of Claim 5, wherein the second planetary gear set, the fourth rotatable shaft, the first synchronizer clutch and the second synchronizer clutch, are arranged parallel to the third rotatable shaft.

7. The continuously variable transmission of Claim 6, further comprising a reverse synchronizer clutch operably coupled to the second sun gear.

8. The continuously variable transmission of Claim 5, further comprising a locking clutch operably coupled to the first planetary gear set, wherein the locking clutch is adapted to selectively engage a fixed ratio mode of operation.

9. The continuously variable transmission of Claim 5, further comprising a third gear set operably coupled to the first mode clutch.

10. The continuously variable transmission of Claim 9, further comprising a third synchronizer clutch operably coupled to the third gear set, wherein the third synchronizer clutch is arranged coaxial with the first synchronizer clutch and the second synchronizer clutch.

11. A continuously variable transmission comprising:

a first rotatable shaft operably coupleable to a source of rotational power;

a second rotatable shaft aligned parallel to the main axis, the third rotatable shaft forming a counter axis;

a variator assembly having a first traction ring assembly and a second traction ring assembly in contact with a plurality of balls, wherein each ball of the plurality of balls has a tiltable axis of rotation, the variator assembly is coaxial with the main axis, the first traction ring assembly operably coupled to the first rotatable shaft;

a chain coupling configured to couple to the second traction ring assembly and the second rotatable shaft;

a first mode clutch coaxial with, and coupled to, the second rotatable shaft;

a second-and-reverse mode clutch coaxial with, and coupled to, the second rotatable shaft;

a first gear set operably coupled to the first mode clutch;

a second gear set operably coupled to the second-and-reverse mode clutch;

a first synchronizer clutch operably coupled to the second gear set; and

a second planetary gear set, coaxial to a third rotatable shaft, comprising:

a second ring gear,

a second planet carrier, and

a second sun gear operably coupled to, and coaxial with, the first gear set and the first synchronizer clutch,

wherein the second planet carrier is operably coupled to ground and the second ring gear is configured to couple to transmit an output power.

12. The continuously variable transmission of Claim 11, further comprising a first planetary gearset comprising:

a first sun gear operably coupled to the second rotatable shaft;

a first planet carrier operably coupled to the first rotatable shaft; and

a first ring gear coupled to the second traction ring assembly.

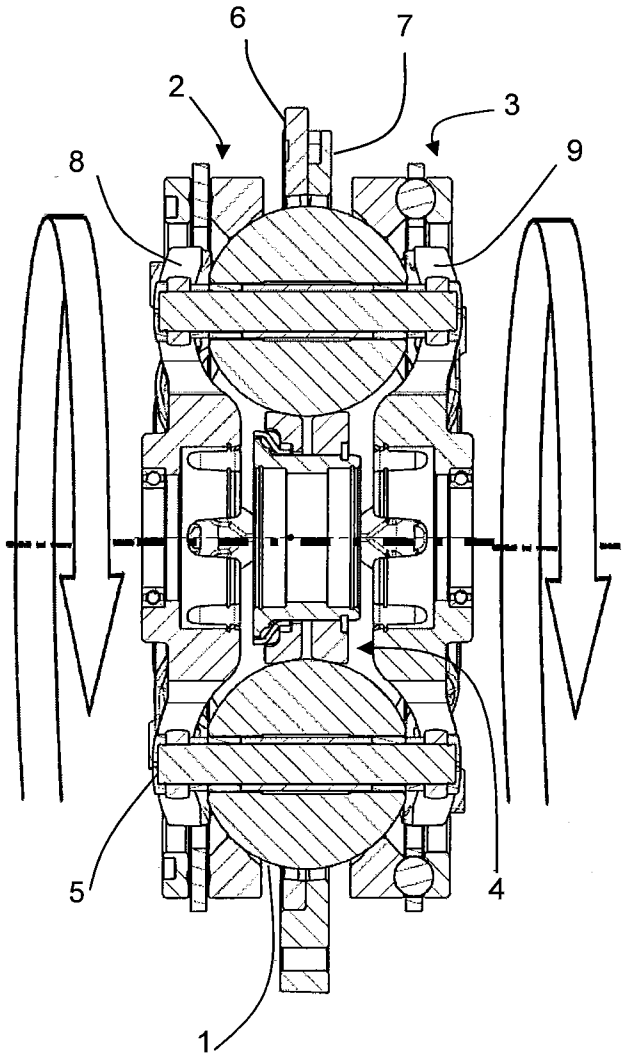


Figure 1

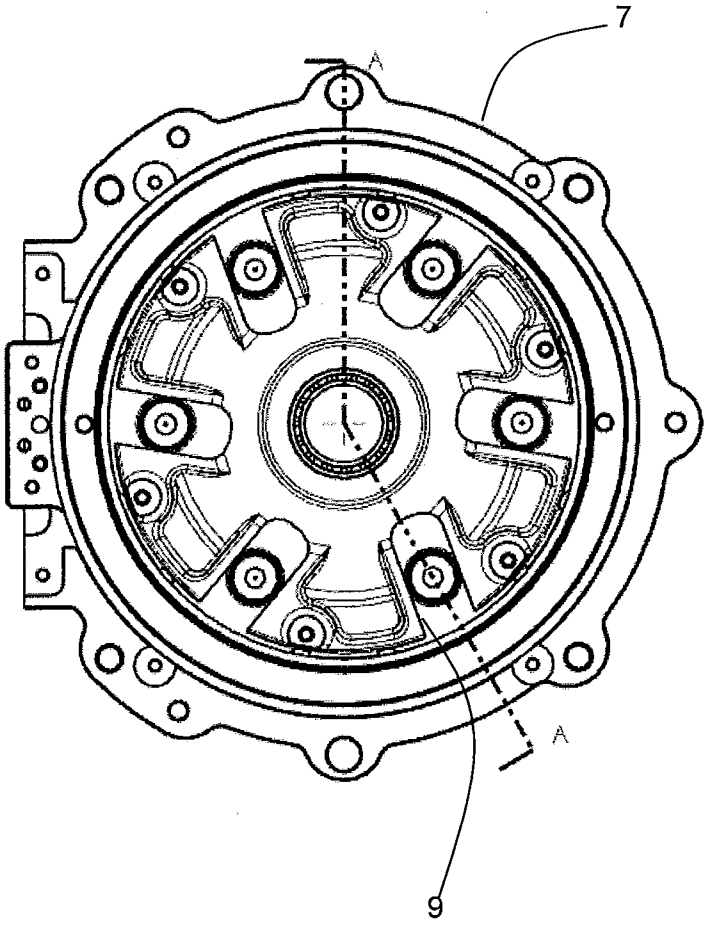


Figure 2

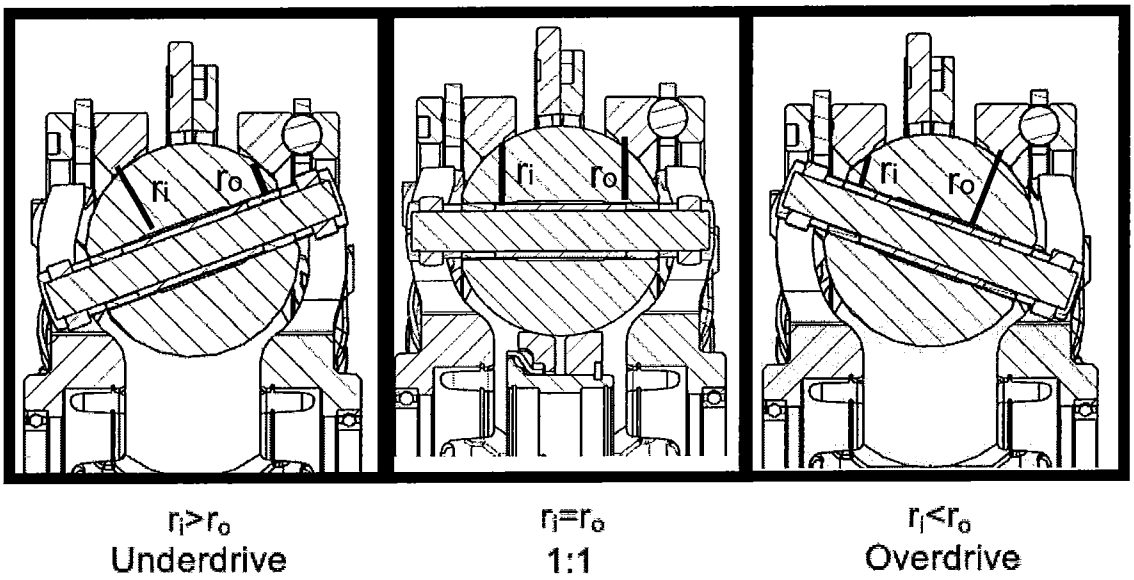


Figure 3

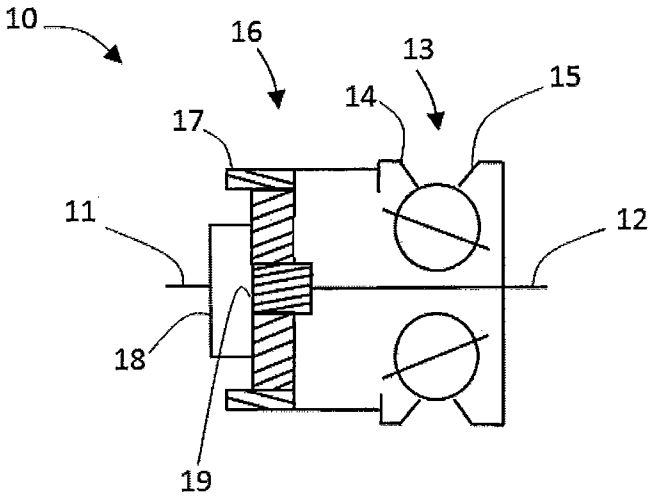


Figure 4

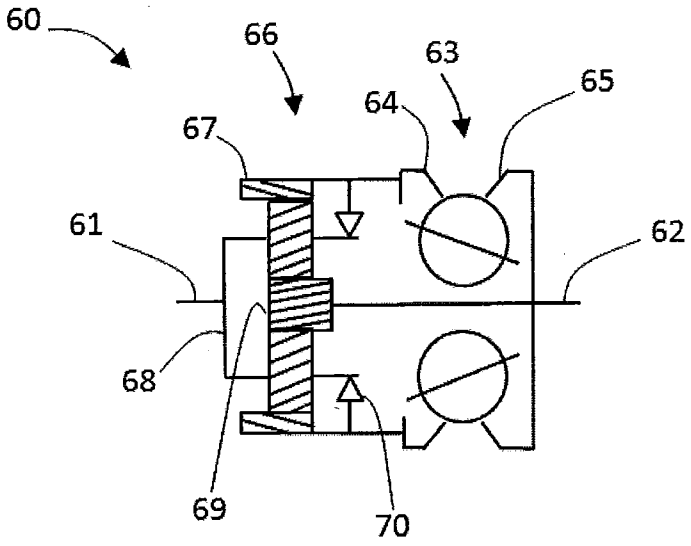


Figure 5

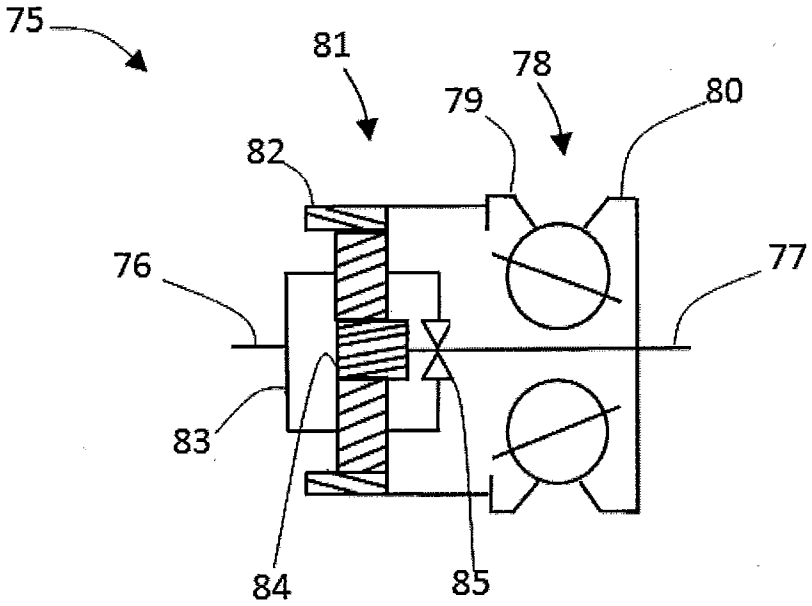


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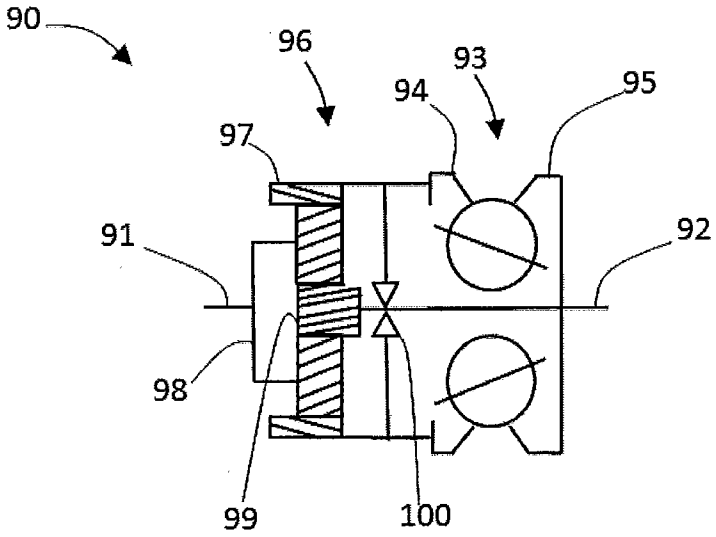


Figure 7

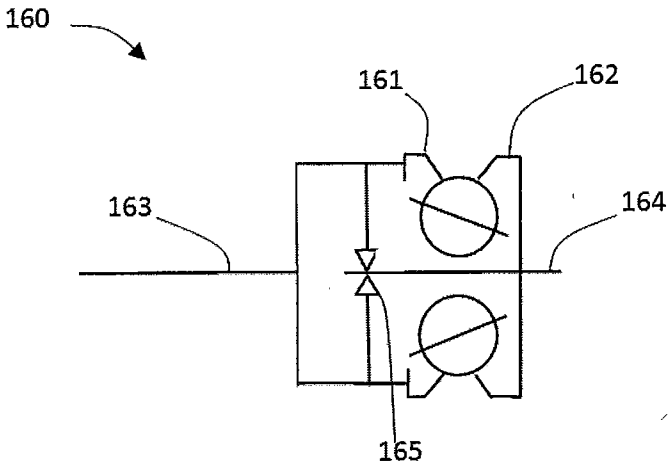


Figure 8

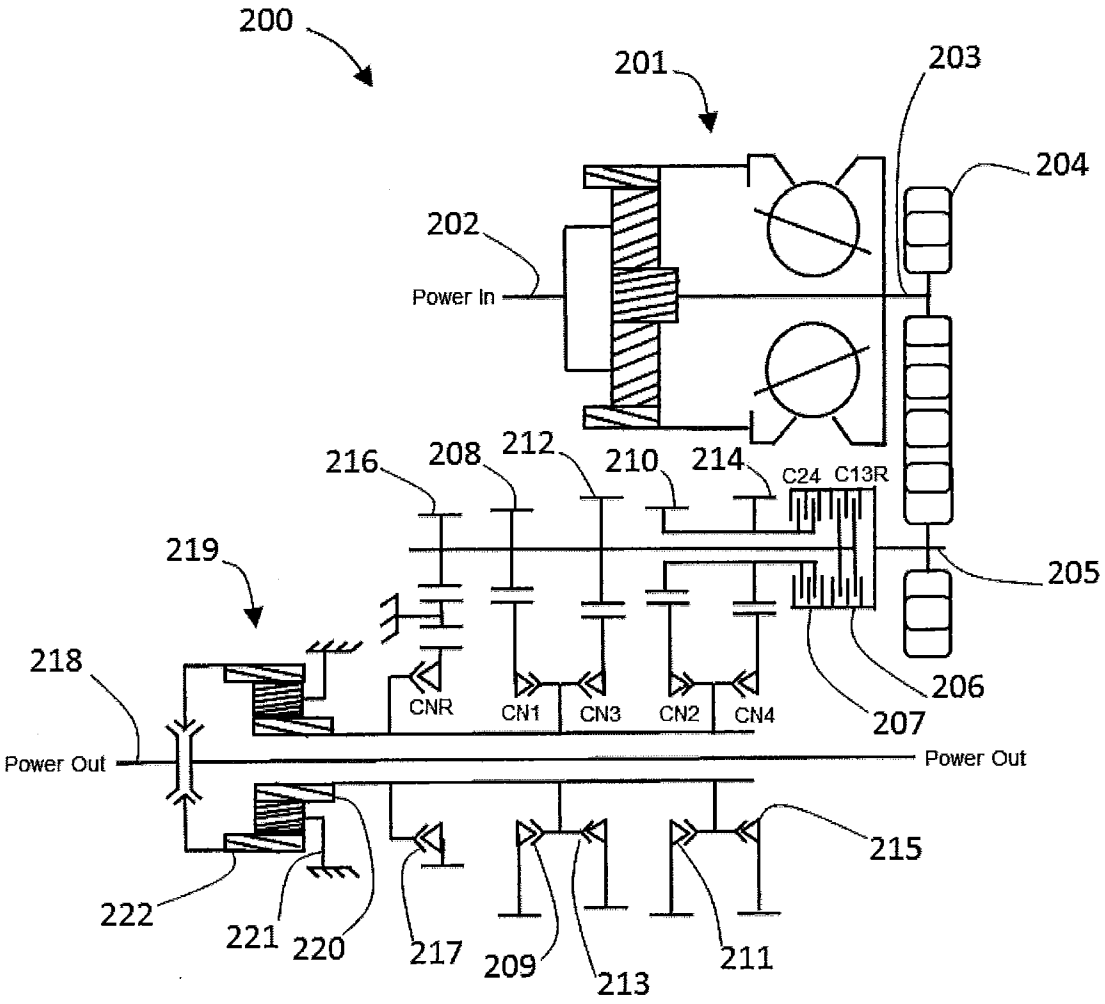


Figure 9

	206 CN13R	207 CN24	209 CN1	211 CN2	213 CN3	215 CN4	217 CNR
Mode 1	X		X				
Mode 2		X		X			
Mode 3	X				X		
Mode 4		X				X	
Reverse	X						X

Figure 10

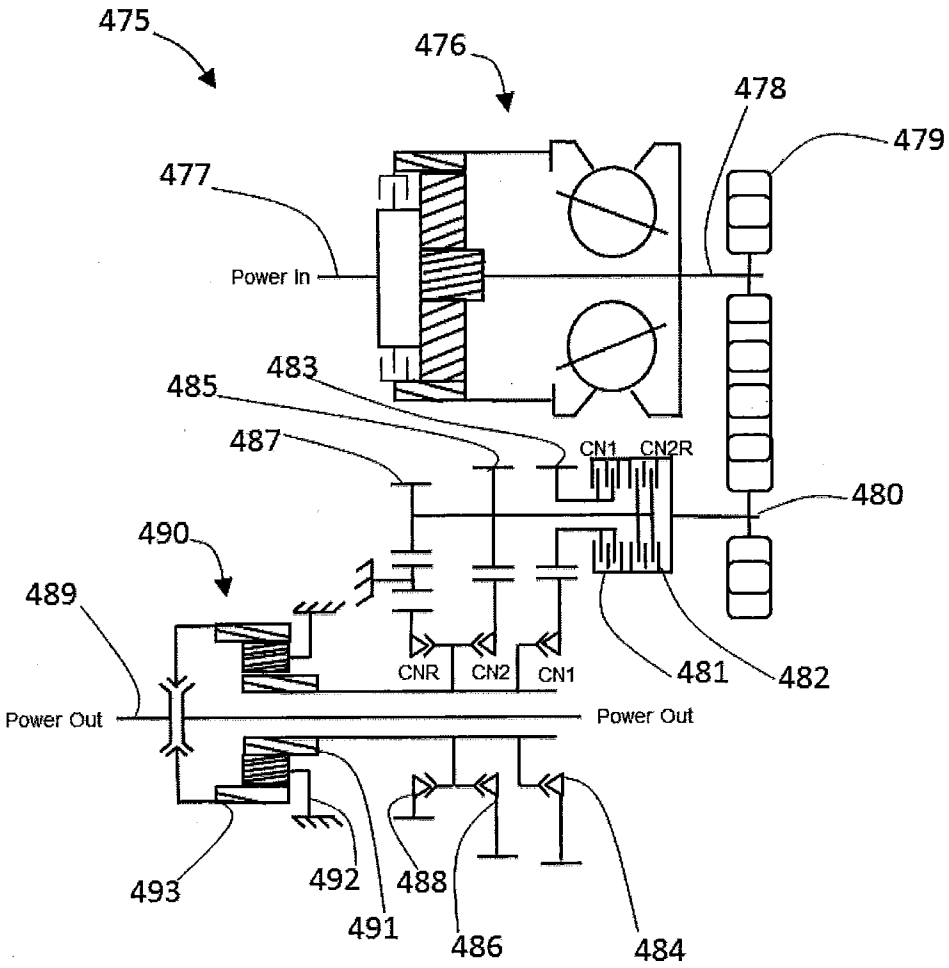


Figure 11

	481 CN1	482 CN2R	484 CN1	486 CN2	488 CNR
Mode 1	X		X		
Mode 2		X		X	
Reverse		X			X

Figure 12

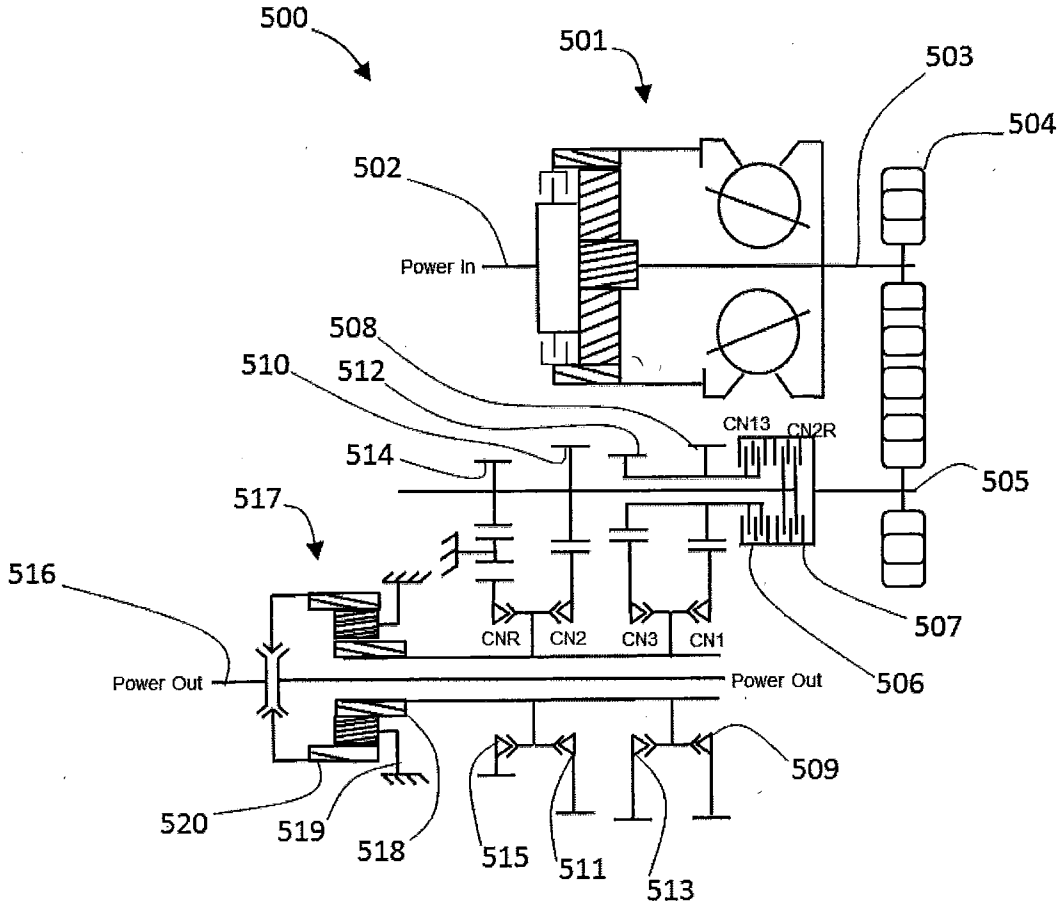


Figure 13

	506 CN13	507 CN2R	509 CN1	511 CN2	513 CN3	515 CNR
Mode 1	X		X			
Mode 2		X		X		
Mode 3	X				X	
Reverse		X				X

Figure 14

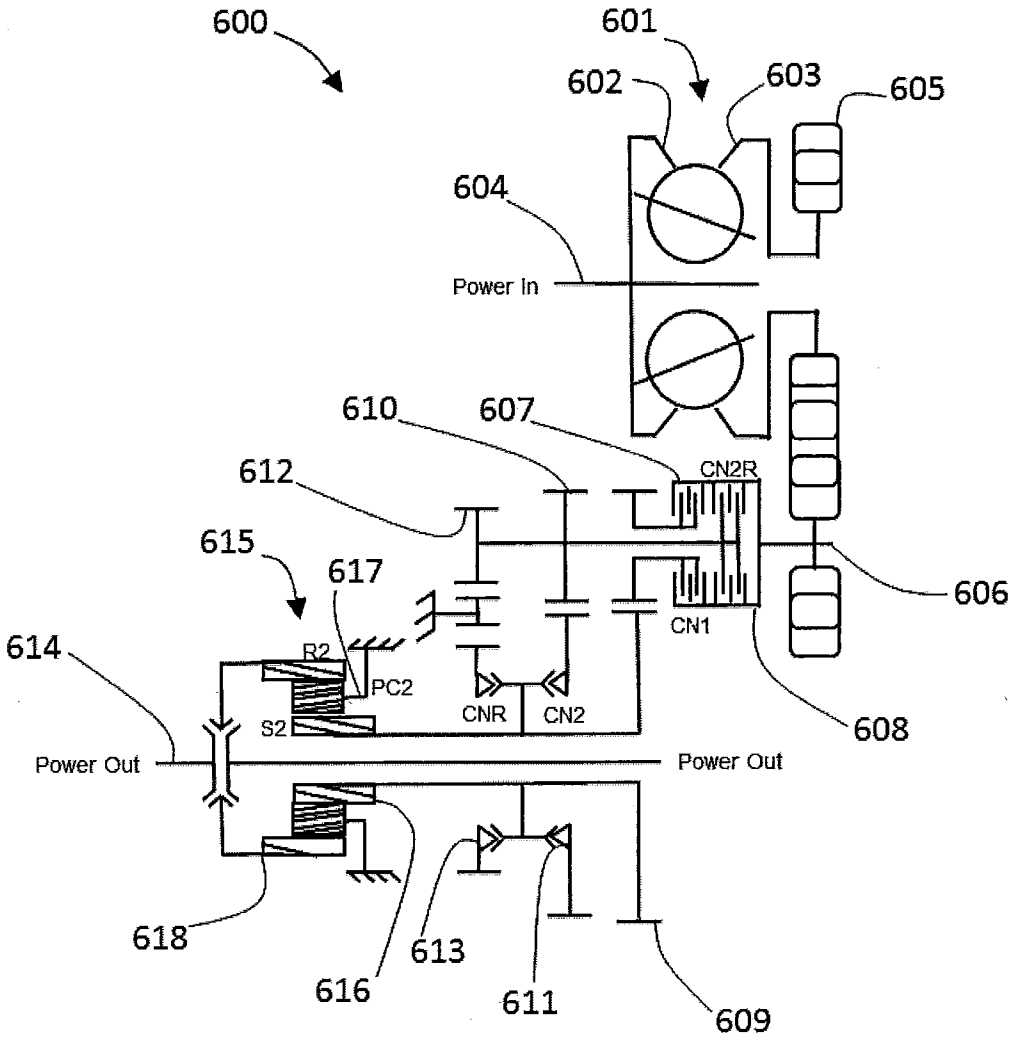


Figure 15

	608 CN2R	607 CN1	611 CN2	613 CNR
Mode 1		X		
Mode 2	X		X	
Reverse	X			X

Figure 16

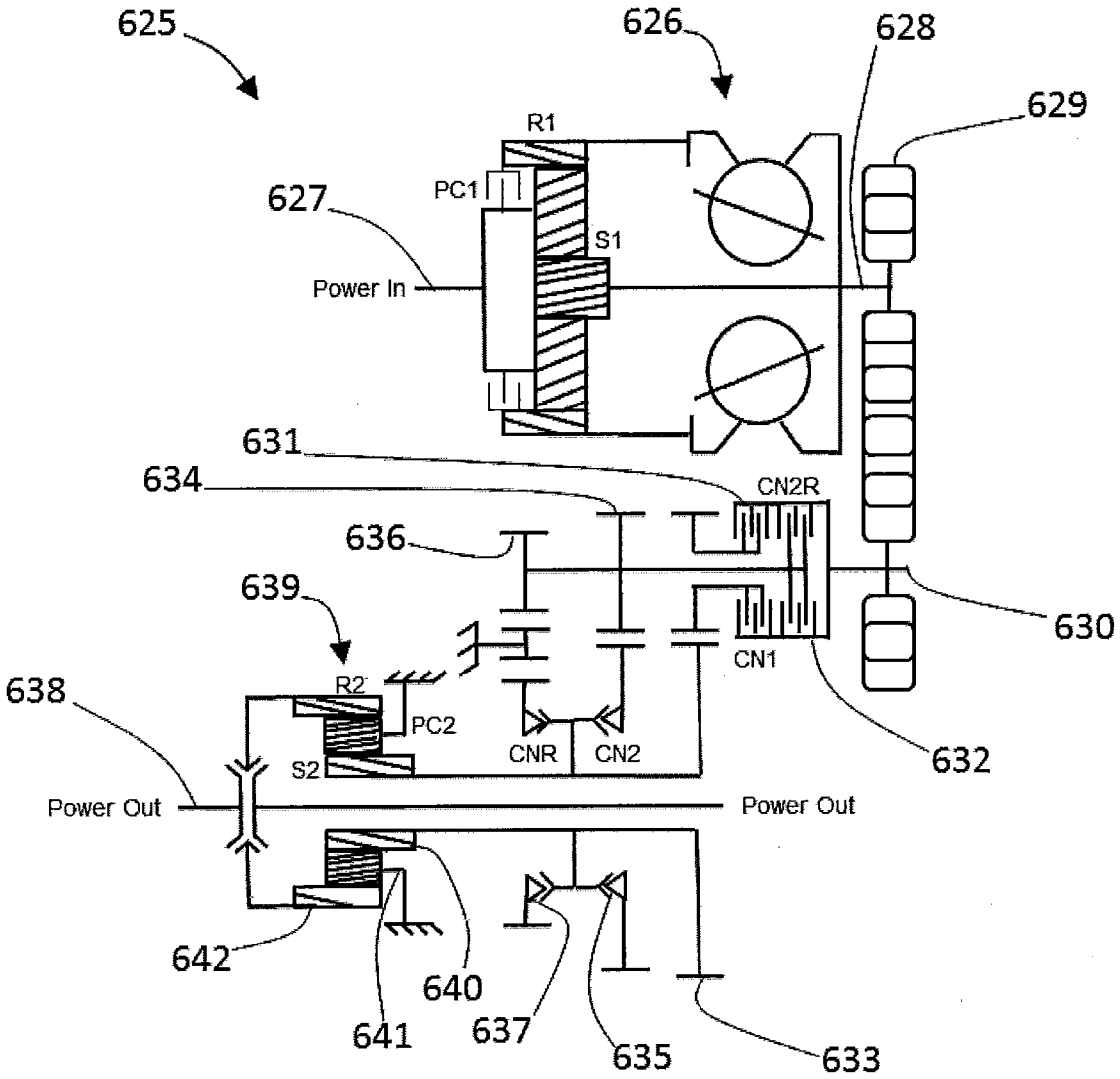
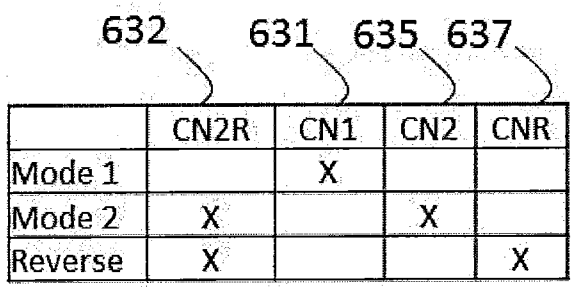


Figure 17



	CN2R	CN1	CN2	CNR
Mode 1		X		
Mode 2	X		X	
Reverse	X			X

Figure 18

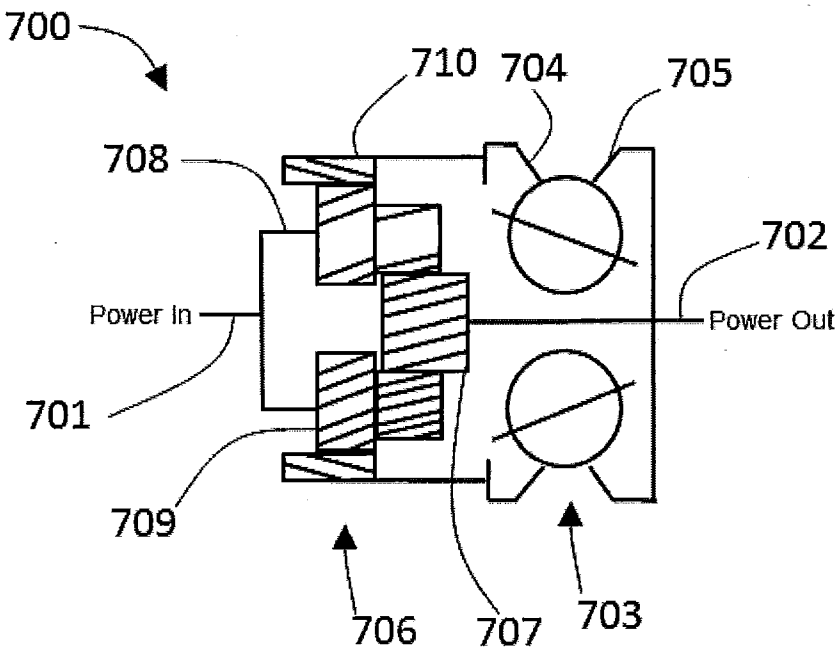


Figure 19

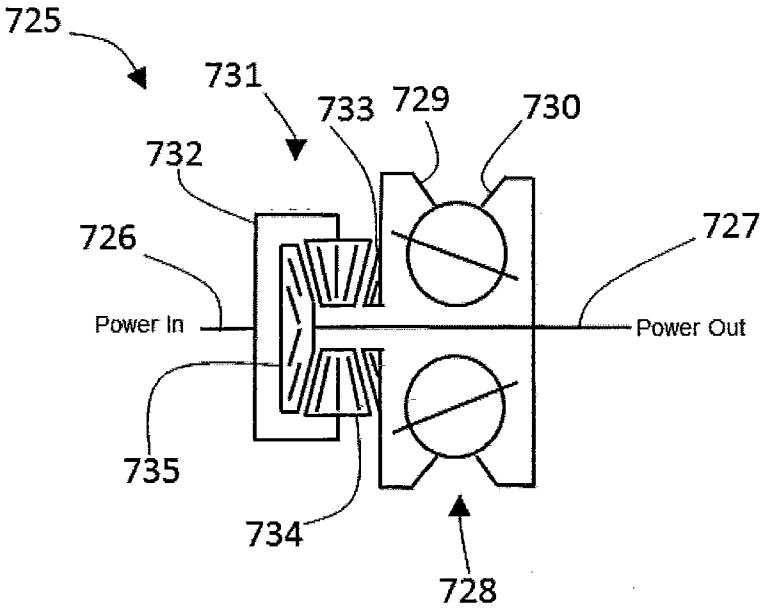


Figure 20

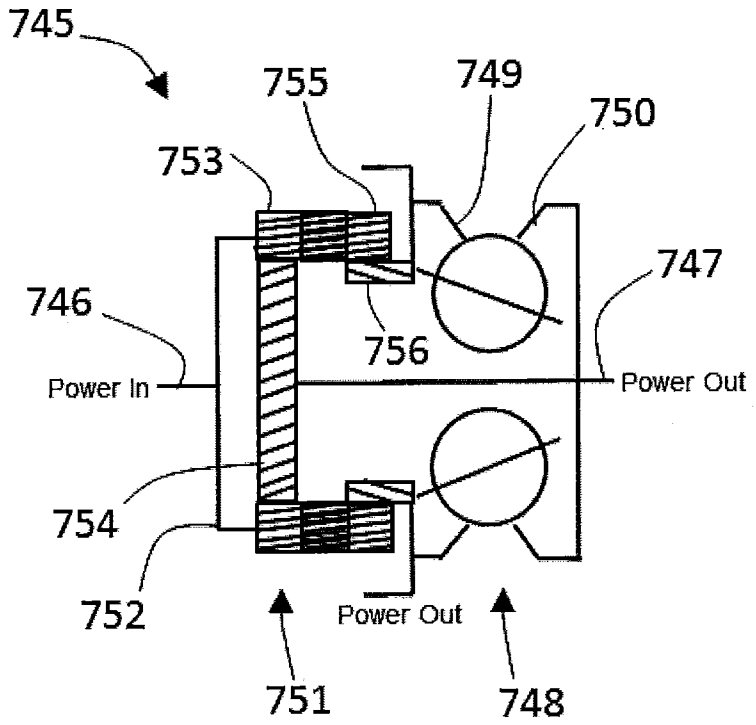


Figure 21

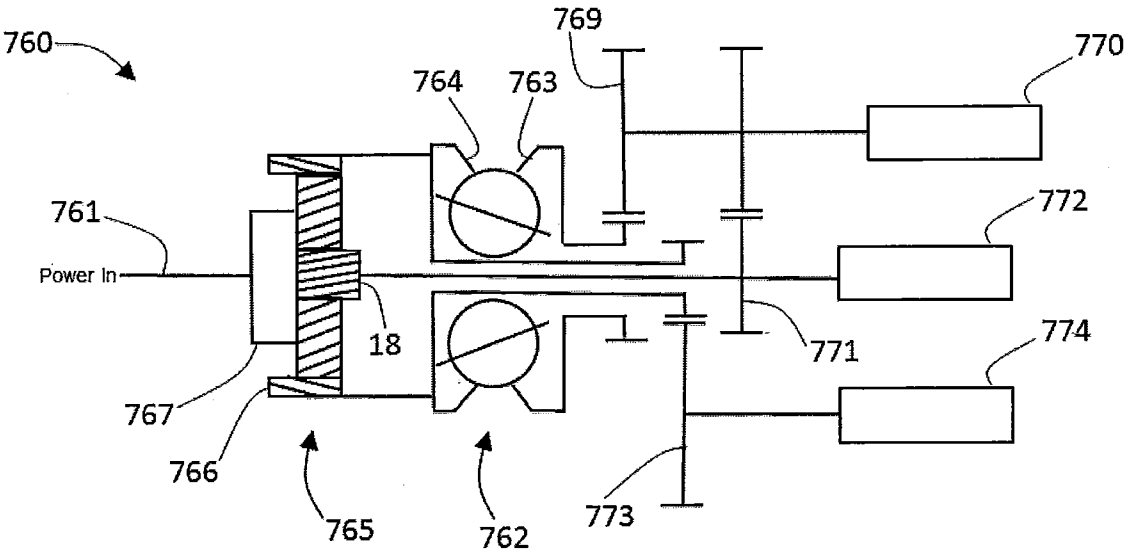


Figure 22

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/033463

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16H3/00 F16H15/28 F16H37/08 F16H3/093
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.
Y	WO 2014/039713 A1 (DANA LTD [US]) 13 March 2014 (2014-03-13) figure 4	1-4
Y	WO 2011/088849 A1 (GM GLOBAL TECH OPERATIONS INC [US]; FUNALOT NICOLAS ALAIN [FR]) 28 July 2011 (2011-07-28) page 4, lines 25-26; figure 1	1-4
Y	DE 10 2005 018978 A1 (BAYERISCHE MOTOREN WERKE AG [DE]) 16 November 2006 (2006-11-16) paragraphs [0002], [0022]; figure 2	1-4
Y	WO 2014/179719 A1 (DANA LTD [US]) 6 November 2014 (2014-11-06) paragraphs [0018] - [0020]; figure 2	1-4

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
24 August 2017	04/09/2017

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

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/033463

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2014/179717 A1 (DANA LTD [US]; BYLTIAUW MATTHIAS W J [BE]) 6 November 2014 (2014-11-06) paragraph [0059]; figure 5B -----	4

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2017/033463

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		US 2015252881 A1	10-09-2015
		WO 2014039713 A1	13-03-2014
WO 2011088849 A1	28-07-2011	NONE	
DE 102005018978 A1	16-11-2006	NONE	
WO 2014179719 A1	06-11-2014	NONE	
WO 2014179717 A1	06-11-2014	NONE	