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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 gear set 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 gear set to selectively couple two of the elements of the planetary gear set 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

5 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

10 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

20 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; a fourth rotatable shaft aligned parallel to the main axis, the fourth rotatable shaft coaxial with the third rotatable shaft; wherein the third rotatable shaft and the fourth rotatable shaft form 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 gear set 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 first chain coupling configured to couple

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to the second rotatable shaft and the third rotatable shaft; a second chain coupling configured to couple to the second rotatable shaft and the fourth rotatable shaft; a first-and-third mode clutch coaxial with, and coupled to, the second rotatable shaft, the first-and-third mode clutch coupled to the first chain coupling; a second-and-fourth mode clutch coaxial with, and coupled to, the second rotatable shaft, the second-and-fourth mode clutch coupled to the second chain coupling; a first gear set operably coupled to the third rotatable shaft; a second gear set operably coupled to the fourth rotatable shaft; a third gear set operably coupled to the third rotatable shaft; a fourth gear set operably coupled to the fourth rotatable shaft; 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 fifth 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; a fourth rotatable shaft aligned parallel to the main axis, the fourth rotatable shaft arranged coaxial to the third rotatable shaft; wherein the third rotatable shaft and the fourth rotatable shaft form 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

gear set 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 first-and-third mode gear set configured to couple to the second rotatable shaft and the third rotatable shaft; a second-and-fourth mode gear set configured to couple to the second rotatable shaft and the fourth rotatable shaft; a first-and-third mode clutch coaxial with, and coupled to, the second rotatable shaft, the first-and-third mode clutch coupled to the first-and-third mode gear set; a second-and-fourth mode clutch coaxial with, and coupled to, the second rotatable shaft, the second-and-fourth mode clutch coupled to the second-and-fourth mode gear set; a first gear set operably coupled to the third rotatable shaft; a second gear set operably coupled to the fourth rotatable shaft; a third gear set operably coupled to the third rotatable shaft; a fourth gear set operably coupled to the fourth rotatable shaft; 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 fifth 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.

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 another 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 of Figure 11.

Figure 13 is a schematic diagram of 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 of Figure 13.

Figure 15 is a schematic diagram of 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 of Figure 15.

Figure 17 is a schematic diagram of a powersplit variator having a stepped planet planetary gear set.

Figure 18 is a schematic diagram of a powersplit variator having a geared differential.

Figure 19 is a schematic diagram of a powersplit variator having dual sun planetary gear set.

Figure 20 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
5 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
10 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
15 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
25 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
30 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.

Turning now to FIG. 9, in some embodiments; a continuously variable transmission (CVT) 25 includes a powersplit variator 26 having a first rotatable shaft 27 and a second rotatable shaft 28. In some embodiments, the powersplit variator 26 is configured such as the variators described in

FIGS. 1-8. The first rotatable shaft 26 is configured to operably couple to a source of rotational power (not shown). The second rotatable shaft 27 is operably coupled to a first mode clutch 29. In some embodiments, the second rotatable shaft 27 is operably coupled to a second-and-reverse mode clutch 30. The first mode clutch 29 is coupled to a chain coupling 31. The chain coupling 31 couples to a third rotatable shaft 32. In some embodiments the third rotatable shaft 32 is optionally configured to be a hollow shaft. The second-and-reverse mode clutch 30 is coupled to a chain coupling 33. The chain coupling 33 is coupled to a fourth rotatable shaft 34. The third rotatable shaft 32 and the fourth rotatable shaft 34 are coaxial. The third rotatable shaft 32 and the fourth rotatable shaft 34 are parallel to the first rotatable shaft 27 and the second rotatable shaft 28. In some embodiments, the fourth rotatable shaft 34 is arranged inside of the third rotatable shaft 32.

Still referring to FIG. 9, in some embodiments; the CVT 25 includes a first gear set 35 operably coupled to the third rotatable shaft 32. The first gear set 35 is coupled to the third rotatable shaft 32. The CVT 25 includes a second gear set 37 operably coupled to the fourth rotatable shaft 34. The second gear set 37 is coupled to a second synchronizer clutch 38. The CVT 25 includes a reverse gear set 43 operably coupled to the fourth rotatable shaft 34. The reverse gear set 43 is coupled to a reverse synchronizer clutch 44. In some embodiments, the CVT 25 includes a planetary gear set 45 having a sun gear 46, a planet carrier 47, and a ring gear 48. The planet carrier 47 is coupled to a grounded member of the CVT 25 such as a housing (not shown). It should be appreciated that the final drive gearing for the CVT 25 is within a designer's means to achieve a certain vehicle packaging and performance. The second synchronizer clutch 38 and the reverse synchronizer clutch 44 are operably coupled to the sun gear 46. The second synchronizer clutch 38, the reverse synchronizer clutch 44, and the planetary gear set 45 are arranged coaxial with a fifth rotatable shaft 49. The fifth rotatable shaft 49 is arranged parallel to the third rotatable shaft 32 and the fourth rotatable shaft 34. The fifth rotatable shaft 49 is configured to transmit an output power.

Referring now to FIG. 10, during operation of the CVT 25, 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 25. The table depicted in FIG. 10, lists the modes of operation for the CVT 25 and indicates with an "x" the corresponding clutch engagement. For mode 1 operation, the first mode clutch 29 is engaged. For mode 2 operation, the second-and-reverse mode clutch 30 and the second synchronizer clutch 38 are engaged. For reverse mode operation, the second-and-reverse mode clutch 30 and the reverse synchronizer clutch 44 are engaged. In some embodiments, the powersplit variator 26 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 reached 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.

Turning now to FIG. 11, in some embodiments; a continuously variable transmission (CVT) 125 includes a powersplit variator 126 having a first rotatable shaft 127 and a second rotatable shaft 128. In some embodiments, the powersplit variator 126 is configured such as the variators described in FIGS. 1-8. The first rotatable shaft 126 is configured to operably couple to a source of rotational power (not shown). The second rotatable shaft 127 is operably coupled to a first-and-third mode clutch 129. In some embodiments,

the second rotatable shaft 127 is operably coupled to a second-and-reverse mode clutch 130. The first-and-third mode clutch 129 is coupled to a chain coupling 131. The chain coupling 131 couples to a third rotatable shaft 132. In some embodiments the third rotatable shaft 132 is optionally configured to be a hollow shaft. The second-and-reverse mode clutch 130 is coupled to a chain coupling 133. The chain coupling 133 is coupled to a fourth rotatable shaft 134. The third rotatable shaft 132 and the fourth rotatable shaft 134 are coaxial. The third rotatable shaft 132 and the fourth rotatable shaft 134 are parallel to the first rotatable shaft 127 and the second rotatable shaft 128. In some embodiments, the fourth rotatable shaft 132 is arranged inside of the third rotatable shaft 132.

Still referring to FIG. 11, in some embodiments; the CVT 125 includes a first gear set 135 operably coupled to the third rotatable shaft 132. The first gear set 135 is coupled to a first synchronizer clutch 136. The CVT 125 includes a second gear set 137 operably coupled to the fourth rotatable shaft 134. The second gear set 137 is coupled to a second synchronizer clutch 138. The CVT 125 includes a third gear set 139 operably coupled to the third rotatable shaft 132. The third gear set 139 is coupled to a third synchronizer clutch 140. The CVT 125 includes a reverse gear set 143 operably coupled to the fourth rotatable shaft 134. The reverse gear set 143 is coupled to a reverse synchronizer clutch 144. In some embodiments, the CVT 125 includes a planetary gear set 145 having a sun gear 146, a planet carrier 147, and a ring gear 148. The planet carrier 147 is coupled to a grounded member of the CVT 125 such as a housing (not shown). The first synchronizer clutch 136, the second synchronizer clutch 138, the third synchronizer clutch 140, and the reverse synchronizer clutch 144 are operably coupled to the sun gear 146. The first synchronizer clutch 136, the second synchronizer clutch 138, the third synchronizer clutch 140, the reverse synchronizer clutch 144, and the planetary gear set 145 are arranged coaxial with a fifth rotatable shaft 149. The fifth rotatable shaft 149 is arranged parallel to the third rotatable shaft 132 and the fourth rotatable shaft 134. The fifth rotatable shaft 149 is configured to transmit an output power.

Referring now to FIG. 12, during operation of the CVT 125, 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 125. The table depicted in FIG. 12, lists the modes of operation for the CVT 125 and indicates with an "x" the corresponding clutch engagement. For mode 1 operation, the first-and-third mode clutch 129 and the first synchronizer clutch 136 are engaged. For mode 2 operation, the second-and-reverse mode clutch 130 and the second synchronizer clutch 138 are engaged. For mode 3 operation, the first-and-third mode clutch 129 and the third synchronizer clutch 140 are engaged. For reverse mode operation, the second-and-reverse mode clutch 130 and the reverse synchronizer clutch 144 are engaged. In some embodiments, the powersplit variator 126 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. 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 reached 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.

Turning now to FIG. 13, in some embodiments; a continuously variable transmission (CVT) 225 includes a powersplit variator 226 having a first rotatable shaft 227 and a second rotatable shaft 228. In some embodiments, the powersplit variator 226 is configured such as the variators described in

FIGS. 1-8. The first rotatable shaft 226 is configured to operably couple to a source of rotational power (not shown). The second rotatable shaft 227 is operably coupled to a first-and-third mode clutch 229. In some embodiments, the second rotatable shaft 227 is operably coupled to a second-and-fourth mode clutch 230. The first-and-third mode clutch 229 is coupled to a chain coupling 231. The chain coupling 231 couples to a third rotatable shaft 232. In some embodiments the third rotatable shaft 232 is optionally configured to be a hollow shaft. The second-and-fourth mode clutch 230 is coupled to a chain coupling 233. The chain coupling 233 is coupled to a fourth rotatable shaft 234. The third rotatable shaft 232 and the fourth rotatable shaft 234 are coaxial. The third rotatable shaft 232 and the fourth rotatable shaft 234 are parallel to the first rotatable shaft 227 and the second rotatable shaft 228. In some embodiments, the fourth rotatable shaft 232 is arranged inside of the third rotatable shaft 232.

Still referring to FIG. 13, in some embodiments; the CVT 225 includes a first gear set 235 operably coupled to the third rotatable shaft 232. The first gear set 235 is coupled to a first synchronizer clutch 236. The CVT 225 includes a second gear set 237 operably coupled to the fourth rotatable shaft 234. The second gear set 237 is coupled to a second synchronizer clutch 238. The CVT 225 includes a third gear set 239 operably coupled to the third rotatable shaft 232. The third gear set 239 is coupled to a third synchronizer clutch 240. The CVT 225 includes a fourth gear set 241 operably coupled to the fourth rotatable shaft 234. The fourth gear set 241 is coupled to a fourth synchronizer clutch 242. The CVT 225 includes a reverse gear set 243 operably coupled to the fourth rotatable shaft 234. The reverse gear set 243 is coupled to a reverse synchronizer clutch 244. In some embodiments, the CVT 225 includes a planetary gear set 245 having a sun gear 246, a planet carrier 247, and a ring gear 248. The planet carrier 247 is coupled to a grounded member of the CVT 225 such as a housing (not shown). The first synchronizer clutch 236, the second synchronizer clutch 238, the third synchronizer clutch 240, the fourth synchronizer clutch 242, and the reverse synchronizer clutch 244 are operably coupled to the sun gear 246. The first synchronizer clutch

236, the second synchronizer clutch 238, the third synchronizer clutch 240, the fourth synchronizer clutch 242, the reverse synchronizer clutch 244, and the planetary gear set 245 are arranged coaxial with a fifth rotatable shaft 249.

The fifth rotatable shaft 249 is arranged parallel to the third rotatable shaft 232 and the fourth rotatable shaft 234. The fifth rotatable shaft 249 is configured to transmit an output power.

Referring now to FIG. 14, during operation of the CVT 225, 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 225. The table depicted in FIG. 14, lists the modes of operation for the CVT 225 and indicates with an "x" the corresponding clutch engagement. For mode 1 operation, the first-and-third mode clutch 229 and the first synchronizer clutch 236 are engaged. For mode 2 operation, the second-and-fourth mode clutch 230 and the second synchronizer clutch 238 are engaged. For mode 3 operation, the first-and-third mode clutch 229 and the third synchronizer clutch 240 are engaged. For mode 4 operation, the second-and-fourth mode clutch 230 and the fourth synchronizer clutch 242 are engaged. For reverse mode operation, the second-and-fourth mode clutch 230 and the reverse synchronizer clutch 244 are engaged. In some embodiments, the powersplit variator 226 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. 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, mode 4, or reverse operation to transmit power through fixed gear ratios and effectively bypass the variator.

Passing now to FIG. 15, in some embodiments; a continuously variable transmission (CVT) 250 includes a powersplit variator 251 having a first rotatable shaft 252 and a second rotatable shaft 253. In some embodiments, the powersplit variator 251 is configured such as the variators described in FIGS. 1-8. The first rotatable shaft 252 is configured to operably couple to a source of rotational power (not shown). The second rotatable shaft 253 is operably coupled to a first-and-third mode clutch 254. In some embodiments, the second rotatable shaft 253 is operably coupled to a second-and-fourth mode clutch 255. The first-and-third mode clutch 253 is coupled to a first-and-third mode gear set 256. The first-and-third mode gear set 256 couples to a third rotatable shaft 257. In some embodiments the third rotatable shaft 257 is optionally configured to be a hollow shaft. The second-and-fourth mode clutch 255 is coupled to a second-and-fourth mode gear set 258. The second-and-fourth mode gear set 258 is coupled to a fourth rotatable shaft 259. The third rotatable shaft 257 and the fourth rotatable shaft 259 are coaxial. The third rotatable shaft 257 and the fourth rotatable shaft 259 are parallel to the first rotatable shaft 252 and the second rotatable shaft 253. In some embodiments, the fourth rotatable shaft 259 is arranged inside of the third rotatable shaft 257.

Still referring to FIG. 15, in some embodiments; the CVT 250 includes a first gear set 260 operably coupled to the third rotatable shaft 257. The first gear set 260 is coupled to a first synchronizer clutch 261. The CVT 250 includes a second gear set 262 operably coupled to the fourth rotatable shaft 259. The second gear set 262 is coupled to a second synchronizer clutch 263. The CVT 250 includes a third gear set 264 operably coupled to the third rotatable shaft 257. The third gear set 264 is coupled to a third synchronizer clutch 265. The CVT 250 includes a fourth gear set 266 operably coupled to the fourth rotatable shaft 259. The fourth gear set 266 is coupled to a fourth synchronizer clutch 267. The CVT 250 includes a reverse gear set 268 operably coupled to the fourth rotatable shaft 259. The reverse gear set 259 is

coupled to a reverse synchronizer clutch 269. In some embodiments, the CVT 250 includes a planetary gear set 270 having a sun gear 271, a planet carrier 272, and a ring gear 273. In some embodiments, the planetary gear set 270 is a dual pinion planetary having two sets of planet gears supported in the planet carrier 272. The planet carrier 270 is coupled to a grounded member of the CVT 250 such as a housing (not shown). The first synchronizer clutch 261, the second synchronizer clutch 263, the third synchronizer clutch 265, the fourth synchronizer clutch 267, and the reverse synchronizer clutch 269 are operably coupled to the sun gear 271. The first synchronizer clutch 261, the second synchronizer clutch 263, the third synchronizer clutch 265, the fourth synchronizer clutch 267, the reverse synchronizer clutch 269, and the planetary gear set 270 are arranged coaxial with a fifth rotatable shaft 274. The fifth rotatable shaft 274 is arranged parallel to the third rotatable shaft 257 and the fourth rotatable shaft 259. The fifth rotatable shaft 274 is configured to transmit an output power.

Referring now to FIG. 16, during operation of the CVT 250, 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 250. The table depicted in FIG. 16, lists the modes of operation for the CVT 250 and indicates with an "x" the corresponding clutch engagement. For mode 1 operation, the first-and-third mode clutch 254 and the first synchronizer clutch 261 are engaged. For mode 2 operation, the second-and-fourth mode clutch 255 and the second synchronizer clutch 263 are engaged. For mode 3 operation, the first-and-third mode clutch 254 and the third synchronizer clutch 265 are engaged. For mode 4 operation, the second-and-fourth mode clutch 255 and the fourth synchronizer clutch 267 are engaged. For reverse mode operation, the second-and-fourth mode clutch 255 and the reverse synchronizer clutch 269 are engaged. In some embodiments, the powersplit variator 251 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. 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, mode 3, mode 4, 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. 17-20, 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 designers 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. 17, 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. 18, 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. 19, 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. 20, 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.

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WHAT IS CLAIMED IS:

1. A continuously variable transmission comprising:

a first rotatable shaft operably coupleable to a source of rotational
5 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;

a fourth rotatable shaft aligned parallel to the main axis, the fourth
10 rotatable shaft coaxial with the third rotatable shaft, wherein the third rotatable
shaft and the fourth rotatable shaft are coaxial and form 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
15 coaxial with the main axis, the first traction ring assembly operably coupled to
the second rotatable shaft;

a first planetary gear set comprising:

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

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

20 and

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

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

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

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

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

a first gear set operably coupled to the third rotatable shaft;
a second gear set operably coupled to the fourth rotatable shaft;
a third gear set operably coupled to the third rotatable shaft;
a fourth gear set operably coupled to the fourth rotatable shaft;
5 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 fifth rotatable shaft, comprising:
10 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
15 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 fifth rotatable shaft, the first synchronizer clutch,
20 the second synchronizer clutch, the third synchronizer clutch, and the fourth
synchronizer clutch are arranged parallel to the counter axis.

3. The continuously variable transmission of Claim 1, further
comprising a reverse synchronizer clutch operably coupled to the second sun
25 gear and arranged parallel to the counter axis.

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
30 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;

a fourth rotatable shaft aligned parallel to the main axis, the fourth rotatable shaft arranged coaxial to the third rotatable shaft, wherein the third rotatable shaft and the fourth rotatable shaft are coaxial and form 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 gear set 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 first-and-third mode gear set configured to couple to the second rotatable shaft and the third rotatable shaft;

a second-and-fourth mode gear set configured to couple to the second rotatable shaft and the fourth rotatable shaft;

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

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

a first gear set operably coupled to the third rotatable shaft;

a second gear set operably coupled to the fourth rotatable shaft;

a third gear set operably coupled to the third rotatable shaft;
a fourth gear set operably coupled to the fourth rotatable shaft;
a first synchronizer clutch operably coupled to the first gear set;
a second synchronizer clutch operably coupled the second gear set;
5 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 fifth rotatable shaft, comprising:
a second ring gear,
a second planet carrier, and
10 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.

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

20 7. The continuously variable transmission of Claim 5, further
comprising a reverse synchronizer clutch operably coupled to the second sun
gear.

25 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.

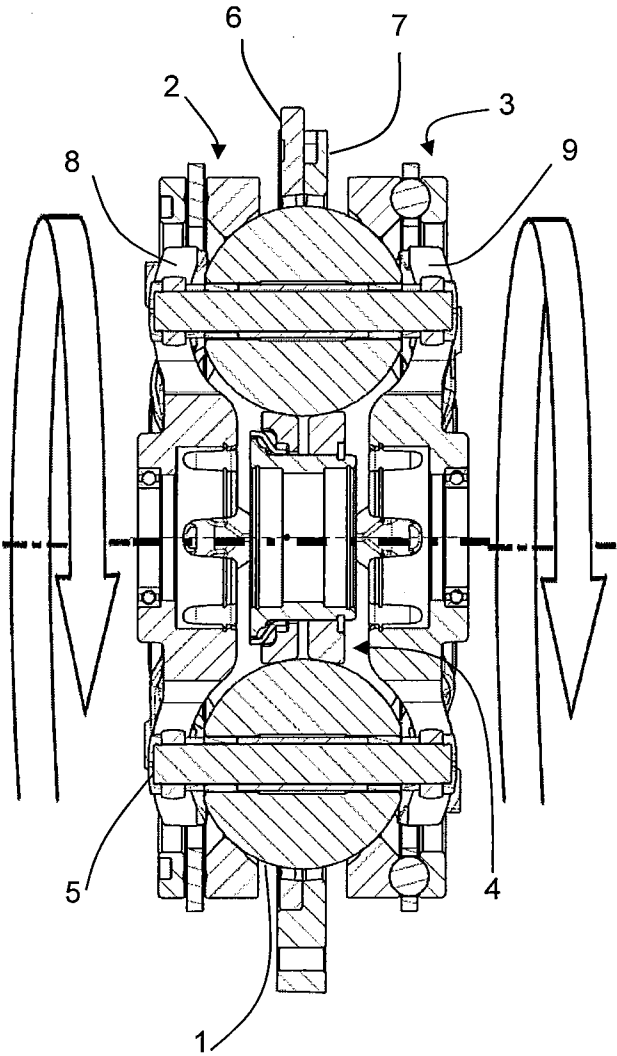


Figure 1

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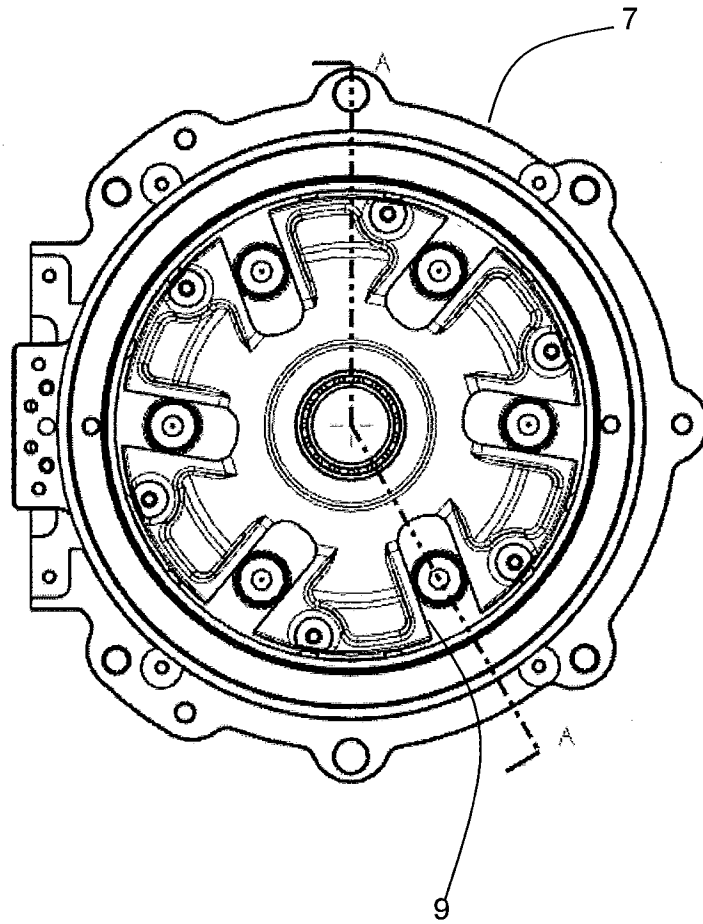


Figure 2

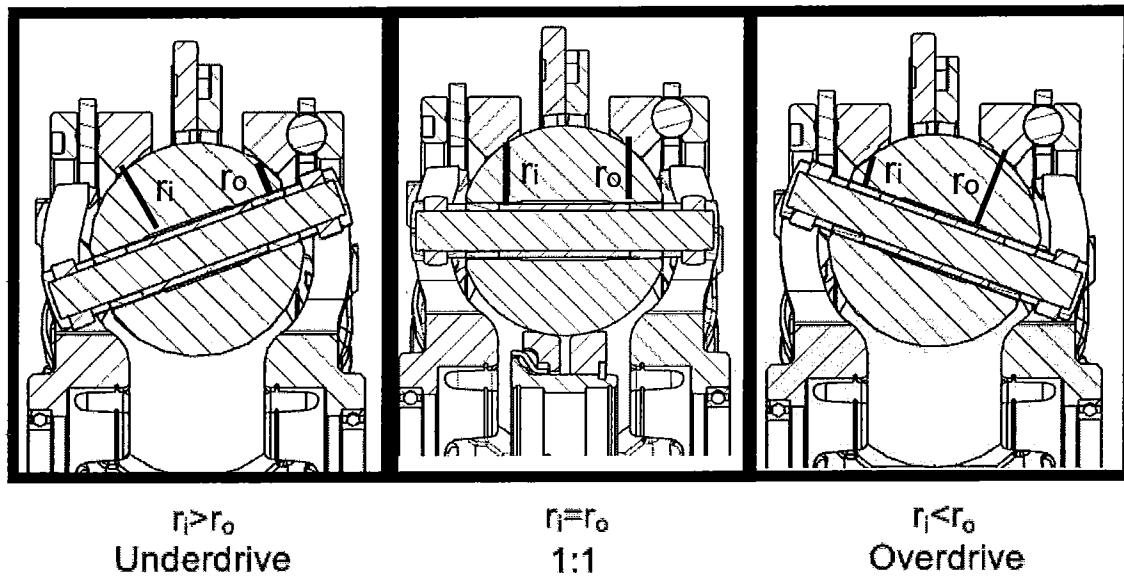


Figure 3

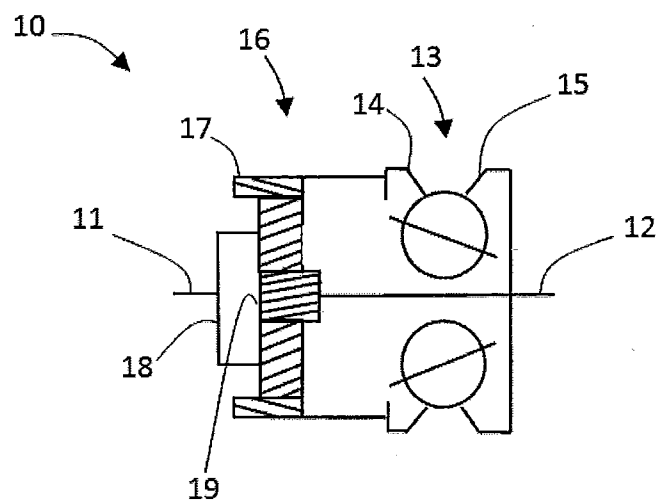


Figure 4

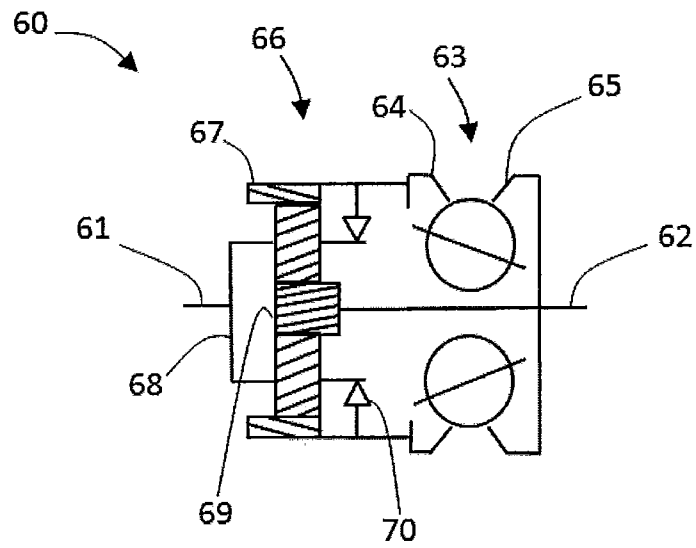


Figure 5

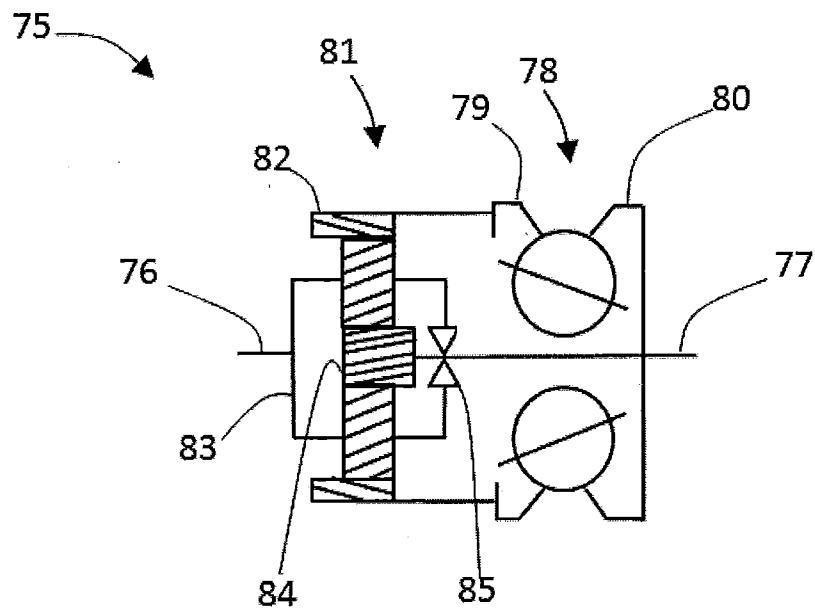


Figure 6

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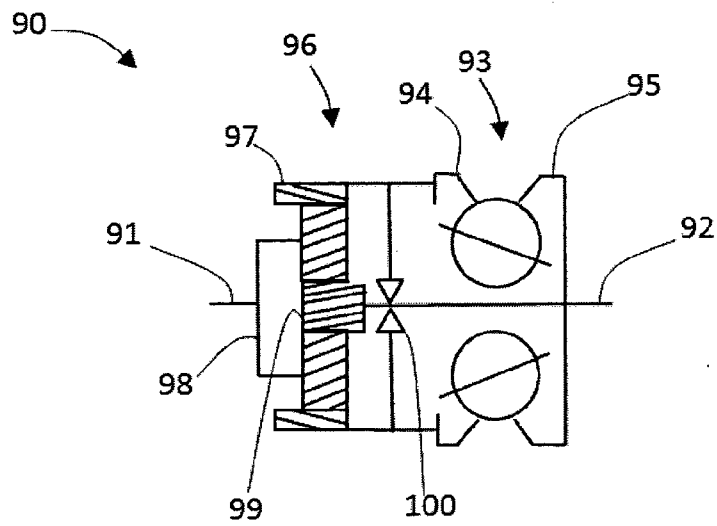


Figure 7

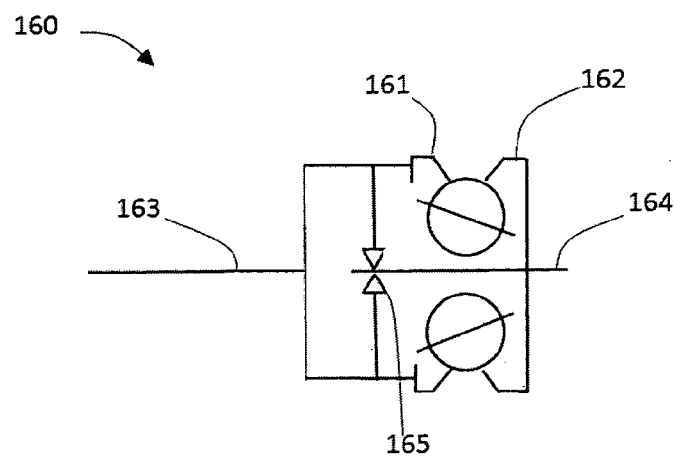


Figure 8

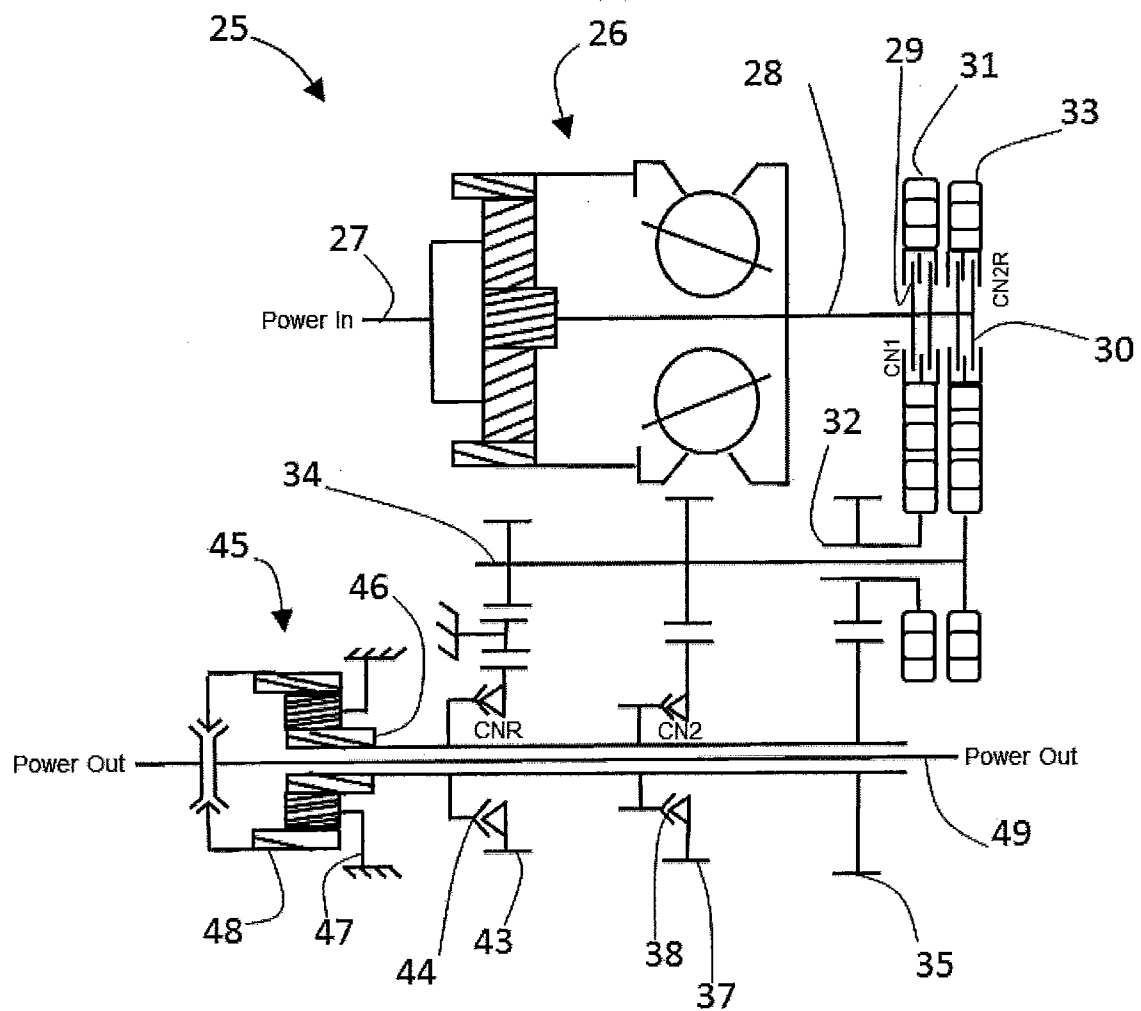


Figure 9

	29 CN1	30 CN2R	38 CN2	44 CNR
Mode 1	X			
Mode 2		X	X	
Reverse		X		X

Figure 10

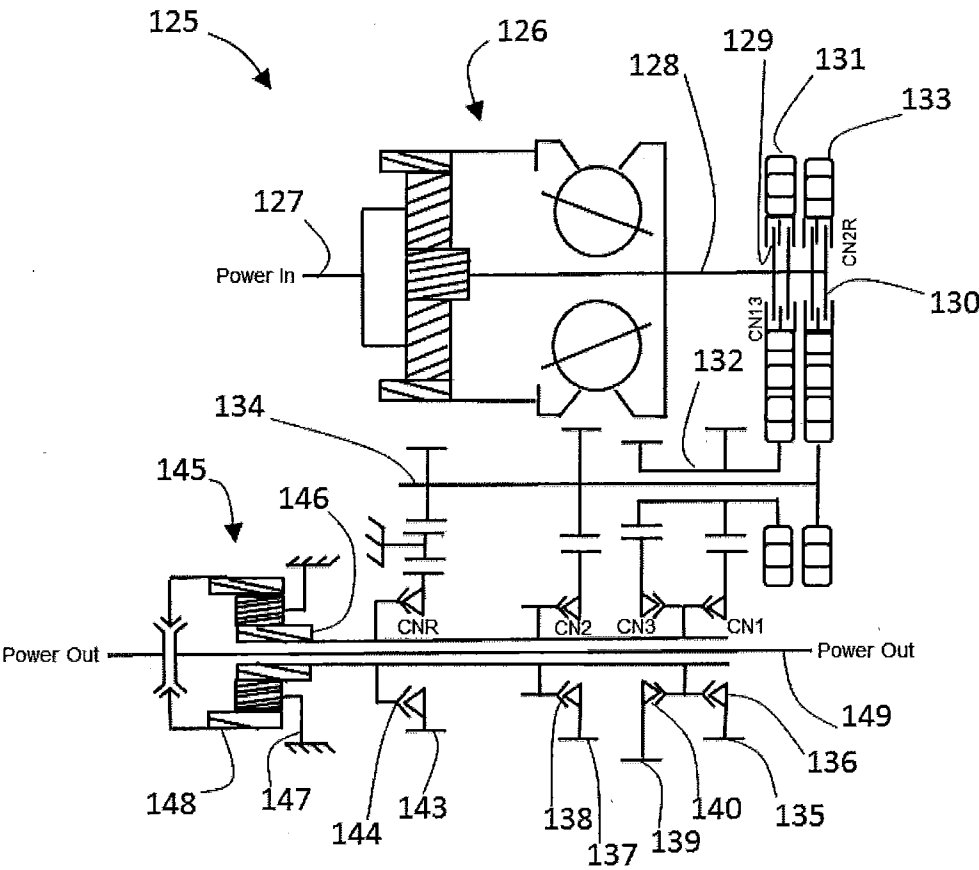


Figure 11

	129	130	136	138	140	144
	CN13	CN2R	CN1	CN2	CN3	CNR
Mode 1	X		X			
Mode 2		X		X		
Mode 3	X				X	
Reverse		X				X

Figure 12

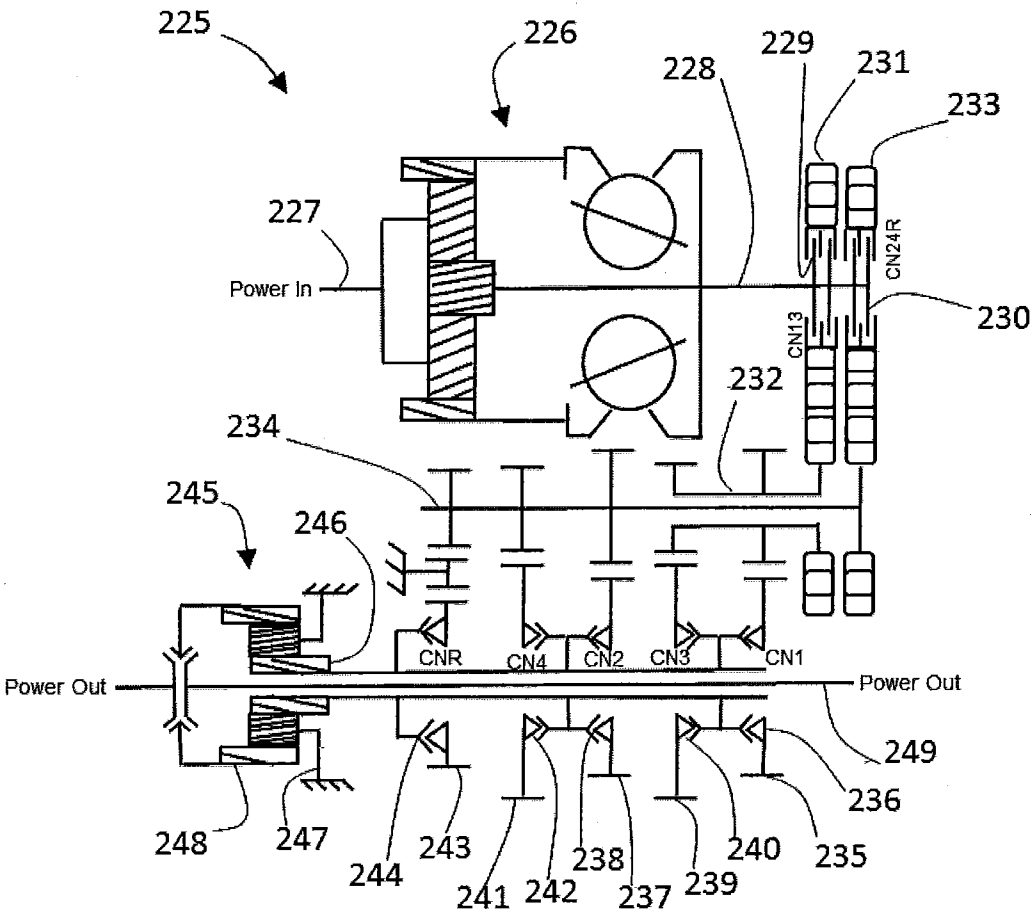


Figure 13

	229 CN13	230 CN24R	236 CN1	238 CN2	240 CN3	242 CN4	244 CNR
Mode 1	X		X				
Mode 2		X		X			
Mode 3	X				X		
Mode 4		X				X	
Reverse		X					X

Figure 14

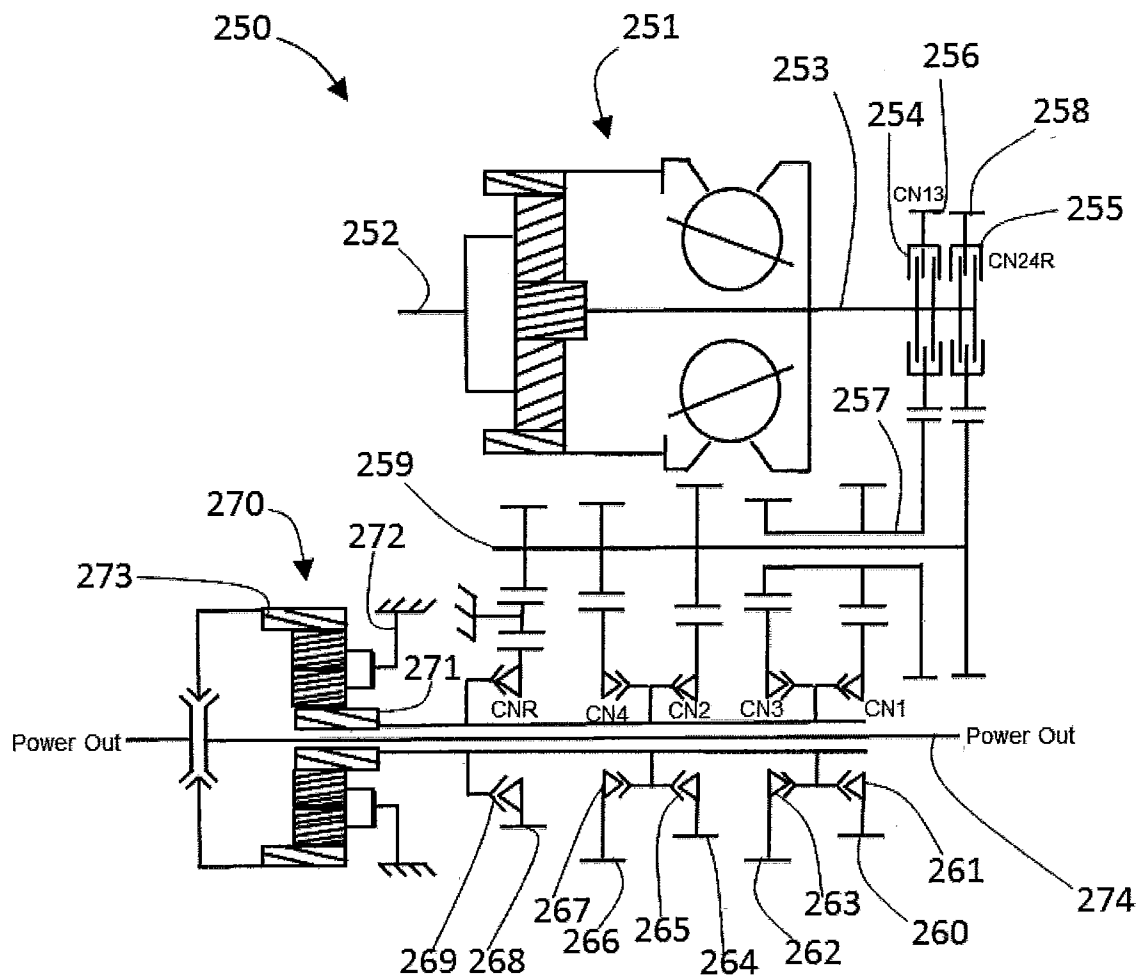


Figure 15

	254 CN13	255 CN24R	261 CN1	263 CN2	265 CN3	267 CN4	269 CNR
Mode 1	X		X				
Mode 2		X		X			
Mode 3	X				X		
Mode 4		X				X	
Reverse		X					X

Figure 16

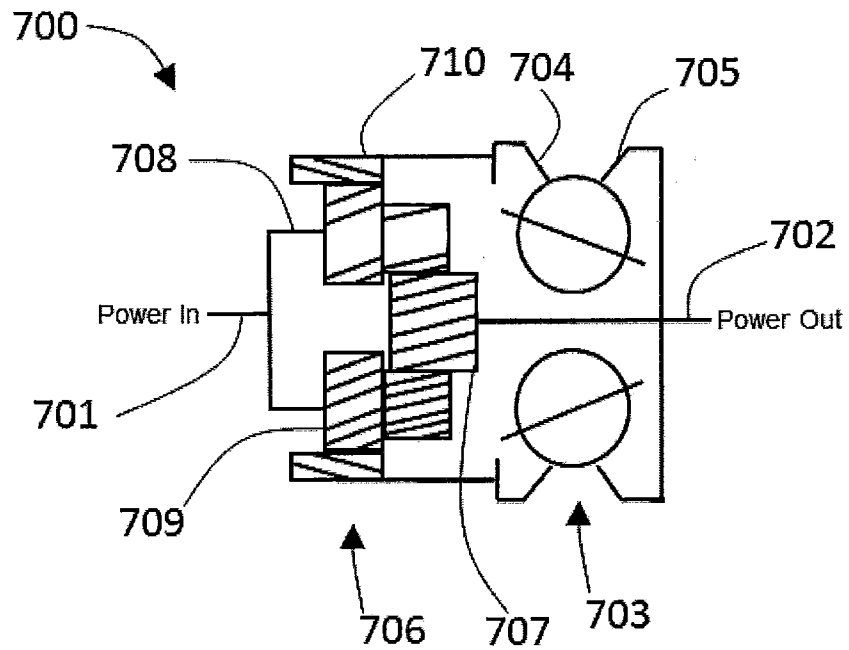


Figure 17

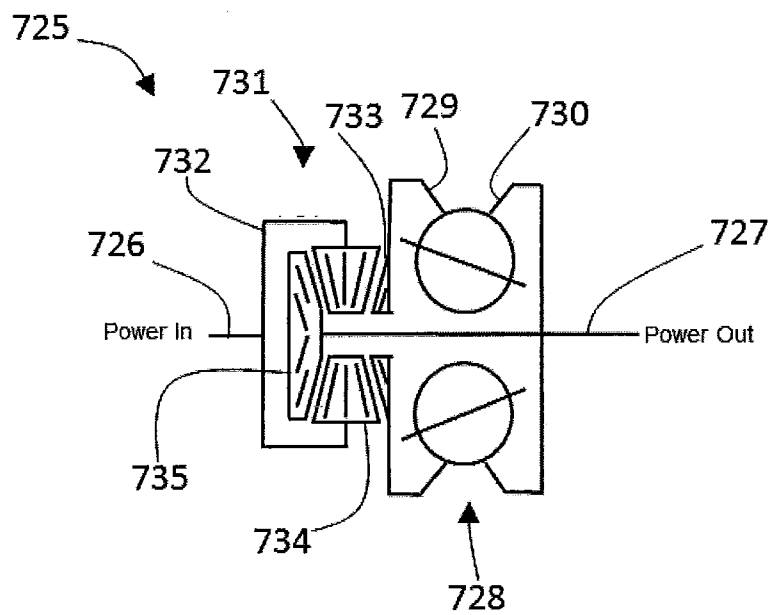


Figure 18

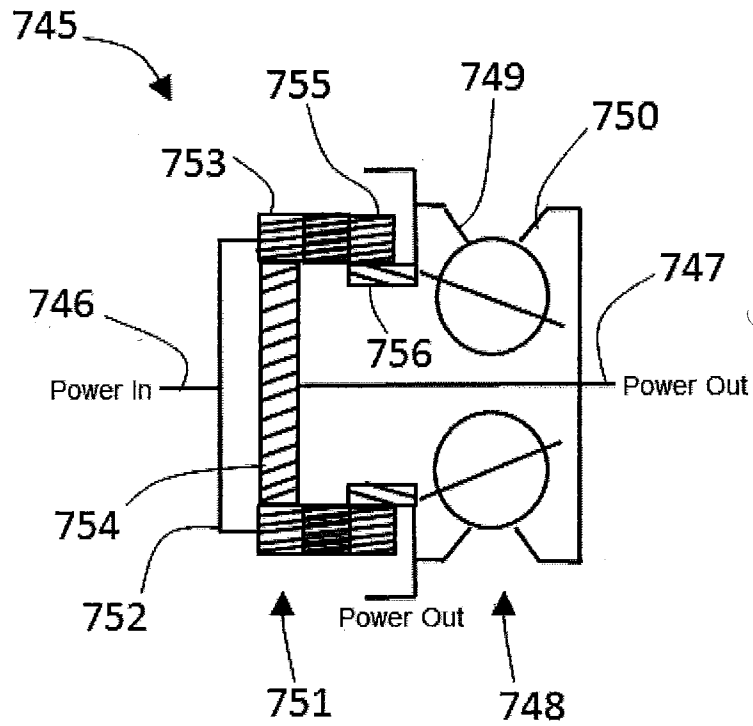


Figure 19

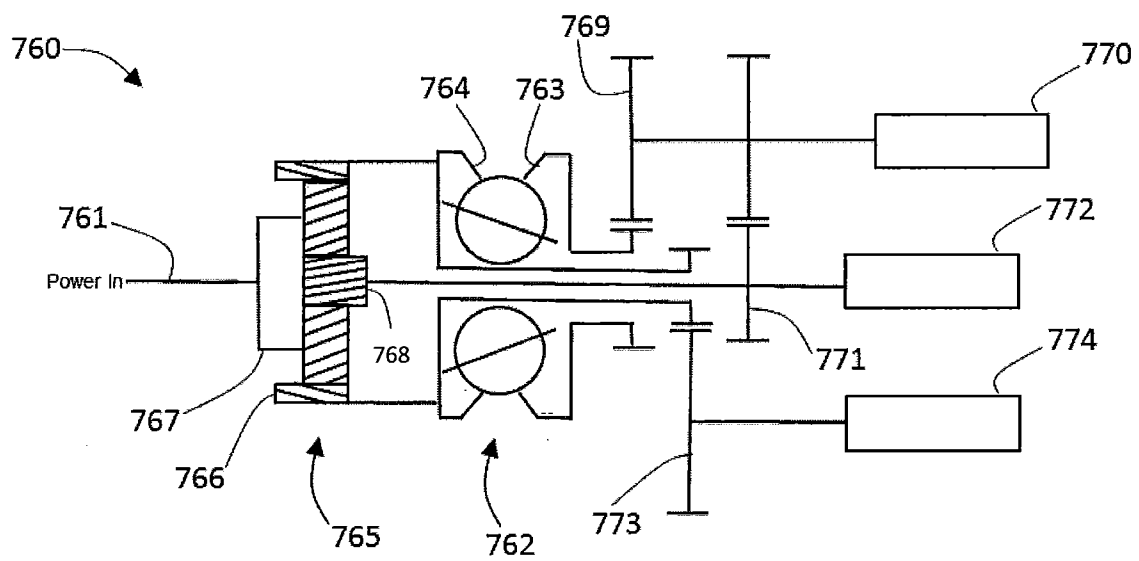


Figure 20

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/033456

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16H15/28 F16H37/08 F16H3/00
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.
A	WO 2014/039713 A1 (DANA LTD [US]) 13 March 2014 (2014-03-13) figure 4 -----	1-4
A	JP S56 148135 U (N/A) 7 November 1981 (1981-11-07) figure 4 -----	1-4
A	DE 10 2011 084623 A1 (ZAHNRADFABRIK FRIEDRICHSHAFEN [DE]) 18 April 2013 (2013-04-18) figure 1 -----	1-4
A	WO 2014/179719 A1 (DANA LTD [US]) 6 November 2014 (2014-11-06) figure 2 -----	1-4



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search

16 October 2017

Date of mailing of the international search report

23/10/2017

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/033456

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2014039713 A1	13-03-2014	CN 104755812 A	01-07-2015
		US 2015252881 A1	10-09-2015
		WO 2014039713 A1	13-03-2014
JP S56148135 U	07-11-1981	NONE	
DE 102011084623 A1	18-04-2013	NONE	
WO 2014179719 A1	06-11-2014	NONE	