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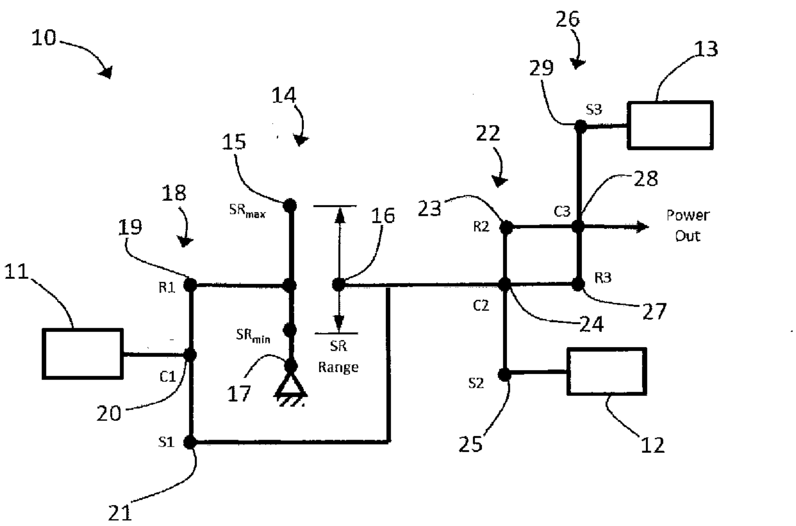

Figure 4

(57) Abstract: A powertrain including: a first and second motor/generators (12, 13); an engine (11); a continuously variable planetary transmission (14); a first planetary gear set (18) having a first ring gear (19) operably coupled to a first traction ring assembly (15) of the continuously variable planetary transmission (14), a first planet carrier (20) operably coupled to the engine (11), and a first sun gear (21) operably coupled to a second traction ring assembly (16) of the continuously variable planetary transmission (14); a second planetary gear set (22) having a second ring gear (23), a second planet carrier (24) operably coupled to the second traction ring assembly (16), and a second sun gear (25) operably coupled to the first motor/generator (12); and a third planetary gear set (26) having a third ring gear (27) operably coupled to the second planet carrier (24), a third planet carrier (28) operably coupled to the second ring gear (23), and a third sun gear (29) operably coupled to the second motor/generator (13).

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POWERTRAIN

RELATED APPLICATION

The present application claims the benefit of U.S. Provisional Application No. 62/541,273 filed on August 4, 2017, which is incorporated herein by reference in its entirety.

BACKGROUND

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

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

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

Regular series-parallel hybrid electric powertrains (powersplit eCVT) are two-motor hybrid electric vehicle (HEV) propulsion systems mated with a planetary gear, and most mild or full parallel hybrid systems are single motor systems with a gearbox or continuously variable transmission coupled with an electric machine. Coupling a ball-type continuously variable planetary (CVP), such as a VariGlide®, with one electric motor/generator enables the creation of a parallel HEV architecture with the

CVP functioning as a continuously variable transmission, and the motor providing the functionality of electric assist, starter motor capability, launch assist and regenerative braking. The dual motor variant opens up the possibility of a series-parallel HEV architecture.

Embodiments disclosed herein, coupled with a hybrid supervisory controller that chooses the path of highest efficiency from engine to wheel, provides a means to optimize the operation of the engine and motor/generator, thereby providing a hybrid powertrain that will operate at the best potential overall efficiency point in any mode and also provide torque variability leading to the best combination of powertrain performance and fuel efficiency that will exceed current industry standards especially in the mild-hybrid and parallel hybrid light vehicle segments.

SUMMARY

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

In some embodiments, the powertrain further includes a disconnect clutch adapted to selectively couple the second planet carrier to the third ring gear.

In some embodiments, the powertrain further includes a first-reverse clutch adapted to selectively couple the third ring gear to a grounded member.

In some embodiments, the powertrain further includes a first-second-third mode clutch adapted to selectively couple the second traction ring assembly to the third sun gear.

In some embodiments, the powertrain further includes a second-and-fourth mode clutch adapted to selectively couple the second sun gear to a grounded member.

In some embodiments, the powertrain further includes a third-and-fourth mode clutch adapted to selectively couple the second traction ring assembly to the second planet carrier.

In some embodiments, the powertrain further includes a reverse clutch adapted to selectively couple the second traction ring assembly to the second sun gear.

INCORPORATION BY REFERENCE

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

BRIEF DESCRIPTION OF THE DRAWINGS

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

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

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

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

Figure 4 is a schematic lever diagram of an electric hybrid powertrain having a ball-type variator, two motor/generators and an engine.

Figure 5 is a schematic lever diagram of an electric hybrid powertrain incorporating a ball-type variator, two motor/generators, an engine, and a disconnect clutch.

Figure 6 is a schematic lever diagram of an electric hybrid powertrain having a ball-type variator, two motor/generators, an engine, and a number of mode clutches.

Figure 7 is a table depicting modes of operation of the electric hybrid powertrain of Figure 6.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Powertrains provided herein relate to electric powertrain configurations and architectures that will be used in hybrid vehicles. The powertrain and/or drivetrain configurations use a ball-type planetary style continuously variable transmission, such as the VariGlide®, in order to couple power sources used in a hybrid vehicle, for example, combustion engines (internal or external), motors, generators, batteries, and gearing.

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

The preferred embodiments will now be described with reference to the accompanying figures, wherein like numerals refer to like elements throughout. The terminology used in the descriptions below is not to be interpreted in any limited or restrictive manner simply because it is used in conjunction with detailed descriptions of certain specific embodiments. Furthermore, the embodiments include 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, includes a number of balls (planets, spheres) 1, depending on the application, two ring (disc) assemblies with a conical surface contact with the balls, as input (first) ring 2 and output (second) ring 3, and an idler (sun) assembly 4 as shown on FIG. 1. Sometimes, the input ring 2 is referred to in illustrations and referred to in text by the label "R1". The output ring 3 is referred to in illustrations and referred to in text by the label "R2". The idler (sun) assembly 4 is referred to in illustrations and referred to in text by the label "S". The balls are mounted on tiltable axles 5, themselves held in a carrier (stator, cage) assembly having a first carrier member 6 operably coupled to a second carrier member 7. Sometimes, the carrier assembly is denoted in illustrations and referred to in text by the label "C". These labels are collectively referred to as nodes ("R1", "R2", "S", "C"). The first carrier member 6 rotates with respect to the second carrier member 7, and vice versa.

In some embodiments, the first carrier member 6 is substantially fixed from rotation while the second carrier member 7 is configured to rotate with respect to the first carrier member, and vice versa.

In some embodiments, the first carrier member 6 is provided with a number of radial guide slots 8. The second carrier member 7 is provided with a number of radially offset guide slots 9, as illustrated in FIG. 2. The radial guide slots 8 and the radially offset guide slots 9 are adapted to guide the tiltable axles 5. The axles 5 are adjusted to achieve a desired ratio of input speed to output speed during operation of the CVT.

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

The working principle of such a CVP of FIG. 1 is shown on FIG. 3. The CVP itself works with a traction fluid. The lubricant (i.e. traction fluid) 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. The embodiments disclosed here are related to a variator and/or a CVT using generally spherical planets each having a tiltable axis of rotation that is adjusted to achieve a desired ratio of input speed to output speed during operation.

In some embodiments, adjustment of said axis of rotation involves angular misalignment of the planet axis in a first plane in order to achieve an angular adjustment of the planet axis in a second plane that is substantially perpendicular to the first plane, thereby adjusting the speed ratio of the variator. The angular misalignment in the first plane is referred to here as “skew”, “skew angle”, and/or “skew condition”.

In some embodiments, a control system coordinates the use of a skew angle to generate forces between certain contacting components in the variator that will tilt the planet axis of rotation. The tilting of the planet axis of rotation adjusts the speed ratio of the variator.

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

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

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

It should be noted that hydro-mechanical components such as hydromotors, pumps, accumulators, among others, are capable of being used in place of the electric machines indicated in the figures and accompanying textual description.

Furthermore, it should be noted that embodiments of hybrid architectures disclosed herein incorporate a hybrid supervisory controller that chooses the path of highest efficiency from engine to wheel. Embodiments disclosed herein enable hybrid powertrains that are capable of operating at the best potential overall efficiency point in any mode and also provide torque variability, thereby leading to the optimal combination of powertrain performance and fuel efficiency. It should be understood that the powertrains disclosed herein include multiple mode transmissions having two, three, four, or more modes and are optionally configured to be implemented by hybrid supervisory control processes amongst others.

It should be understood that hybrid vehicles incorporating embodiments of the hybrid architectures disclosed herein are capable of including a number of other powertrain components, such as, but not limited to, high-voltage battery pack with a battery management system or ultracapacitor, on-board charger, DC-DC converters, a variety of sensors, actuators, and controllers, among others.

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

Referring to FIG. 4, in some embodiments, an electric hybrid powertrain 10 includes an engine 11, a first motor/generator 12, and a second motor/generator 13. The electric hybrid powertrain 10 incorporates a variator (CVP) 14, such as the variator depicted in Figure 1-3. The CVP 14 includes a first traction ring assembly 15, a second traction ring assembly 16, and a carrier 17 that is non-rotatable.

In some embodiments, the electric hybrid powertrain 10 includes a first planetary gear set 18 having a first ring gear 19, a first planet carrier 20, and a sun gear 21. The first planet carrier 20 is operably coupled to the engine 11. The first ring gear 19 is operably coupled to the first traction ring assembly 15. The first sun gear 21 is operably coupled to the second traction ring assembly 16.

In some embodiments, the electric hybrid powertrain 10 includes a second planetary gear set 22 having a second ring gear 23, a second planet carrier 24, and a second sun gear 25. The second planet carrier 24 is operably coupled to the second traction ring assembly 16. The second sun gear 25 is operably coupled to the first motor/generator 12.

In some embodiments, the electric hybrid powertrain 10 includes a third planetary gear set 26 having a third ring gear 27, a third planet carrier 28, and a third sun gear 29. The third ring gear 27 is operably coupled to the second planet carrier 24. The third planet carrier 28 is operably coupled to the second ring gear 23. The third sun gear 29 is operably coupled to the second motor/generator 13.

In some embodiments, a rotational power is transmitted out of the electric hybrid powertrain 10 through the third planet carrier 28.

Referring now to FIG. 5, in some embodiments, an electric hybrid powertrain 40 includes an engine 41, a first motor/generator 42, and a second motor/generator 43. The electric hybrid powertrain 40 incorporates a variator (CVP) 44, such as the variator depicted in Figure 1-3. The CVP 44 includes a first traction ring assembly 45, a second traction ring assembly 46, and a carrier 47 that is non-rotatable.

In some embodiments, the electric hybrid powertrain 40 includes a first planetary gear set 48 having a first ring gear 49, a first planet carrier 50, and a sun gear 51. The first planet carrier 50 is operably coupled to the engine 41. The first ring gear 49 is operably coupled to the first traction ring assembly 45. The first sun gear 51 is operably coupled to the second traction ring assembly 46.

In some embodiments, the electric hybrid powertrain 40 includes a second planetary gear set 52 having a second ring gear 53, a second planet carrier 54, and a second sun gear 55. The second planet carrier 54 is operably coupled to the second traction ring assembly 46. The second sun gear 55 is operably coupled to the first motor/generator 42.

In some embodiments, the electric hybrid powertrain 40 includes a third planetary gear set 56 having a third ring gear 57, a third planet carrier 58, and a third sun gear 59. The third ring gear 57 is operably coupled to a disconnect clutch 60. The disconnect clutch 60 is configured to selectively couple the third ring gear 57 to the second planet carrier 54. The third planet carrier 58 is operably coupled to the second ring gear 53. The third sun gear 59 is operably coupled to the second motor/generator 43.

In some embodiments, a rotational power is transmitted out of the electric hybrid powertrain 40 through the third planet carrier 58.

Turning now to FIG. 6, in some embodiments, an electric hybrid powertrain 80 includes an engine 81, a first motor/generator 82, and a second motor/generator 83. The electric hybrid powertrain 80 incorporates a variator (CVP) 84, such as the variator depicted in Figure 1-3. The CVP 84 includes a first traction ring assembly 85, a second traction ring assembly 86, and a carrier 87 that is non-rotatable.

In some embodiments, the electric hybrid powertrain 80 includes a first planetary gear set 88 having a first ring gear 89, a first planet carrier 90, and a sun gear 91. The first planet carrier 90 is operably coupled to the engine 81. The first ring gear

89 is operably coupled to the first traction ring assembly 85. The first sun gear 91 is operably coupled to the second traction ring assembly 86.

In some embodiments, the electric hybrid powertrain 80 includes a second planetary gear set 92 having a second ring gear 93, a second planet carrier 94, and a second sun gear 95. The second planet carrier 94 is operably coupled to the second traction ring assembly 86. The second sun gear 95 is operably coupled to the first motor/generator 82.

In some embodiments, the electric hybrid powertrain 80 includes a third planetary gear set 96 having a third ring gear 97, a third planet carrier 98, and a third sun gear 99.

In some embodiments, the electric hybrid powertrain 80 includes a first-reverse clutch 100 adapted to selectively couple the third ring gear 97 to ground. The electric hybrid powertrain 80 includes a first-second-third mode clutch 101 adapted to selectively couple the second traction ring assembly 86 to the third sun gear 99. The electric hybrid powertrain 80 includes a second-and-fourth mode clutch 102 adapted to selectively couple the second sun gear 95 to ground. The electric hybrid powertrain 80 includes a third-and-fourth mode clutch 103 adapted to selectively couple the second traction ring 86 to the second planet carrier 94. The electric hybrid powertrain 80 includes a reverse clutch 104 adapted to selectively couple the second traction ring assembly 86 to the second sun gear 95. The third ring gear 97 is operably coupled to a disconnect clutch 105. The disconnect clutch 105 is configured to selectively couple the third ring gear 97 to the second planet carrier 94. The third planet carrier 98 is operably coupled to the second ring gear 93. The third sun gear 99 is operably coupled to the second motor/generator 83.

In some embodiments, a rotational power is transmitted out of the electric hybrid powertrain 80 through the third planet carrier 98.

Referring now to FIG. 7, during operation of the electric hybrid powertrain 80, multiple modes of operation are controlled by the engagement and disengagement of clutches to facilitate multiple speed ranges and charging or driving of the electric motor/generators.

For example, a single motor electric low speed mode of operation corresponds to the engagement of the first-reverse clutch 100 and the disengagement of the first-second-third mode clutch 101, the second-and-fourth mode clutch 102, the third-and-fourth mode clutch 103, the reverse clutch 104, and the disconnect clutch 105. A dual motor electric low mode of operation corresponds to the engagement of the first-reverse clutch 100 and the disconnect clutch 105, and the disengagement of the first-second-third mode clutch 101, the second-and-fourth mode clutch 102, the third-and-fourth mode clutch 103, and the reverse clutch 104.

A dual motor electric high speed mode of operation corresponds to the engagement the disconnect clutch 105, and the disengagement of the first-reverse clutch 100, first-second-third mode clutch 101, the second-and-fourth mode clutch 102, the third-and-fourth mode clutch 103, and the reverse clutch 104.

An input split mode of operation corresponds to the engagement of the first-reverse clutch 100 and the third-and-fourth mode clutch 103, and the disengagement of the first-second-third mode clutch 101, the second-and-fourth mode clutch 102, the reverse clutch 104, and the disconnect clutch 105. Typically, an input split mode of operation is characterized by engine power being split through two distinct paths, a mechanical path into the second carrier 94 and out to the wheels through the second ring 93 and third carrier 98 connection, and an electrical path through the second sun 95 and the first motor/generator 82. The ratio of the transmission is thus determined by the loading of the first motor/generator 82 and the ratio of the variator (CVP) 84. A reverse electric mode of operation corresponds to the engagement of the first-reverse clutch 100 and the disengagement of the first-second-third mode clutch 101, the second-and-fourth mode clutch 102, the third-and-fourth mode clutch 103, the reverse clutch 104, and the disconnect clutch 105. Typically, the reverse electric mode of operation corresponds to the second motor/generator 83 having an opposite direction of speed and torque as compared to forward modes of operation.

A compound split mode of operation corresponds to the engagement of the third-and-fourth mode clutch 103 and the disconnect clutch 105, and the disengagement of the first-reverse clutch 100, first-second-third mode clutch 101, the second-and-fourth mode clutch 102, and the reverse clutch 104. Typically, a compound split mode of operation is characterized by the combined (or compounded) operation of the second planetary 92 and the third planetary 96 when the disconnect clutch 105 is applied. The ratio of the transmission is thus determined by the loading of both the first motor/generator 82, the second motor/generator 83, and the ratio of the variator (CVP) 84. A first gear mode of operation is a fixed gear operating mode corresponding to the engagement of the first-reverse clutch 100 and the first-second-third mode clutch 101, and the disengagement of the second-and-fourth mode clutch 102, the third-and-fourth mode clutch 103, the reverse clutch 104, and the disconnect clutch 105. A second gear mode of operation is a fixed gear operating mode corresponding to the engagement of the first-second-third mode clutch 101, the second-and-fourth mode clutch 102, and the disconnect clutch 105, and the disengagement of the first-reverse mode clutch 100, the third-and-fourth mode clutch 103, and the reverse clutch 104. A third gear mode of operation is a fixed gear operating mode corresponding to the engagement of the first-second-third mode clutch 101, the third-and-fourth mode clutch 103, and the disconnect clutch 105, and the disengagement of the first-reverse clutch 100, the second-and-fourth mode clutch 102, and the reverse clutch 104. A fourth gear mode of operation is a fixed gear mode of operation corresponding to the engagement of the second-and-fourth mode clutch 102, the third-and-fourth mode clutch 103, and the disconnect clutch 105, and the disengagement of the first-reverse clutch 100, the first-second-third mode clutch 101, and the reverse clutch 104. A reverse mode of operation corresponds to engagement of the first-reverse clutch 100, the reverse clutch 104, and the disconnect clutch 105, and the disengagement of the first-second-third mode clutch 101, the second-and-fourth mode clutch 102, and the third-and-fourth mode clutch 103.

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

It should be noted that where an engine is described, the engine is capable of being an internal combustion engine (diesel, gasoline, hydrogen) or any powerplant such as a fuel cell system, or any hydraulic/pneumatic powerplant like an air-hybrid system. Along the same lines, the battery pack is capable of being not just a high voltage pack such as lithium ion or lead-acid batteries, but also ultracapacitors or other pneumatic/hydraulic systems such as accumulators, or other forms of energy storage systems.

The electric motor/generators are capable of representing hydromotors actuated by variable displacement pumps, electric machines, or any other form of rotary power such as pneumatic motors driven by pneumatic pumps. The eCVT architectures depicted in the figures and described in text is capable of being extended to create a hydro-mechanical CVT architectures as well for hydraulic hybrid systems.

In some embodiments, electric hybrid powertrains disclosed herein are operably coupled to a wheel drive axle configured to drive a set of vehicle wheels. In some embodiments, the powertrains are operably coupled to a differential implemented to transmit rotational power. The differential is operably coupled to a wheel drive axle and configured to drive a set of vehicle wheels connected to the ends there of.

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

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

Various embodiments as described herein are provided in the Aspects below:

Aspect 1. A powertrain comprising:

a first motor/generator;

a second motor/generator;

an engine;

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

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

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

a third planetary gear set having a third ring gear operably coupled to the second planet carrier, a third planet carrier operably coupled to the second ring gear, and a third sun gear operably coupled to the second motor/generator.

Aspect 2. The powertrain of Aspect 1, further comprising a disconnect clutch adapted to selectively couple the second planet carrier to the third ring gear.

Aspect 3. The powertrain of Aspect 1, further comprising a first-reverse clutch adapted to selectively couple the third ring gear to a grounded member.

Aspect 4. The powertrain of Aspect 1, further comprising a first-second-third mode clutch adapted to selectively couple the second traction ring assembly to the third sun gear.

Aspect 5. The powertrain of Aspect 1, further comprising a second-and-fourth mode clutch adapted to selectively couple the second sun gear to a grounded member.

Aspect 6. The powertrain of Aspect 1, further comprising a third-and-fourth mode clutch adapted to selectively couple the second traction ring assembly to the second planet carrier.

Aspect 7. The powertrain of Aspect 1, further comprising a reverse clutch adapted to selectively couple the second traction ring assembly to the second sun gear.

WHAT IS CLAIMED IS:

1. A powertrain comprising:

a first motor/generator;

a second motor/generator;

an engine;

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

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

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

a third planetary gear set having a third ring gear operably coupled to the second planet carrier, a third planet carrier operably coupled to the second ring gear, and a third sun gear operably coupled to the second motor/generator.

2. The powertrain of Claim 1, further comprising a disconnect clutch adapted to selectively couple the second planet carrier to the third ring gear.

3. The powertrain of Claim 1, further comprising a first-reverse clutch adapted to selectively couple the third ring gear to a grounded member.

4. The powertrain of Claim1, further comprising a first-second-third mode clutch adapted to selectively couple the second traction ring assembly to the third sun gear.

5. The powertrain of Claim 1, further comprising a second-and-fourth mode clutch adapted to selectively couple the second sun gear to a grounded member.

6. The powertrain of Claim 1, further comprising a third-and-fourth mode clutch adapted to selectively couple the second traction ring assembly to the second planet carrier.

7. The powertrain of Claim 1, further comprising a reverse clutch adapted to selectively couple the second traction ring assembly to the second sun gear.

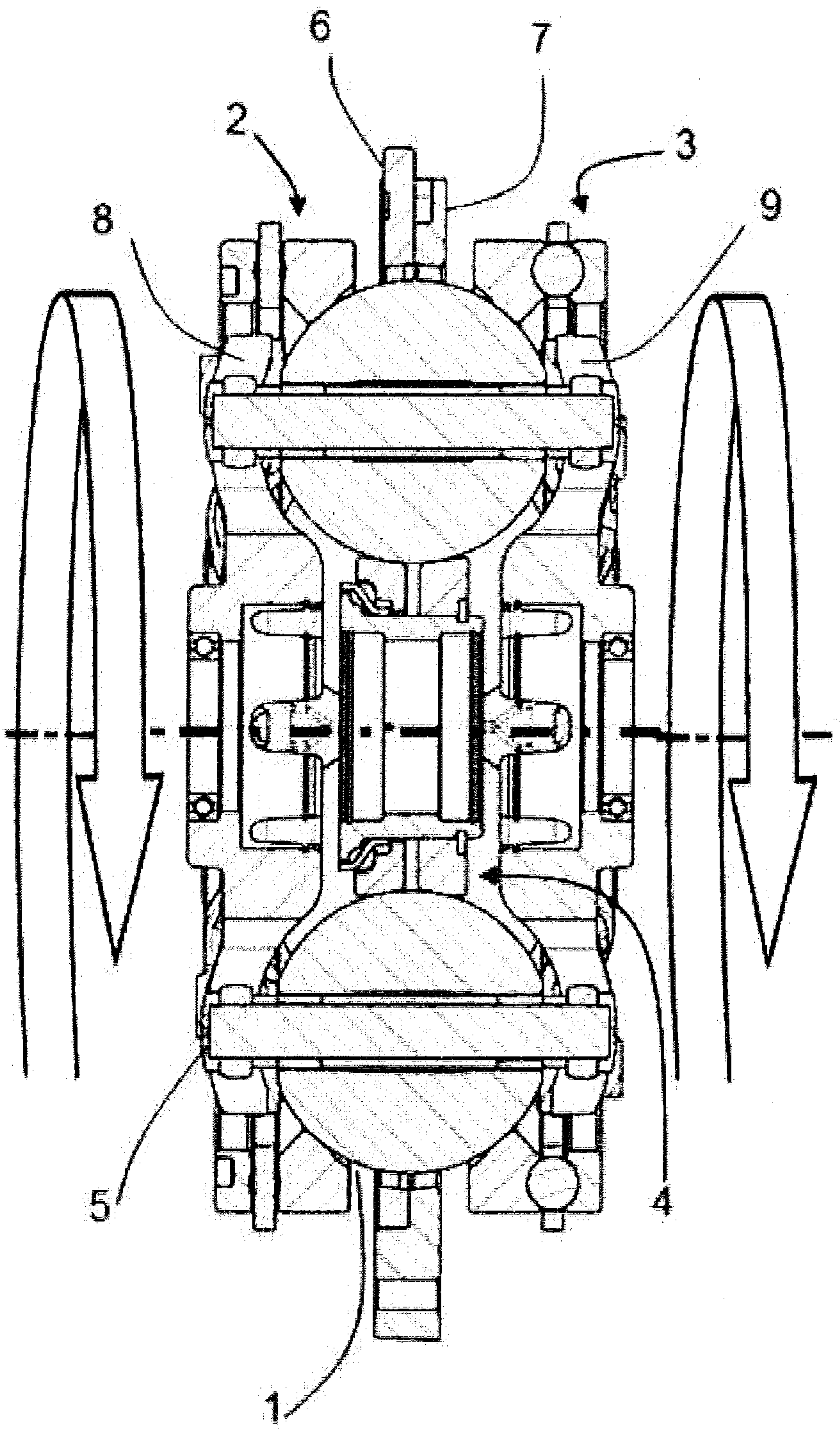


Figure 1

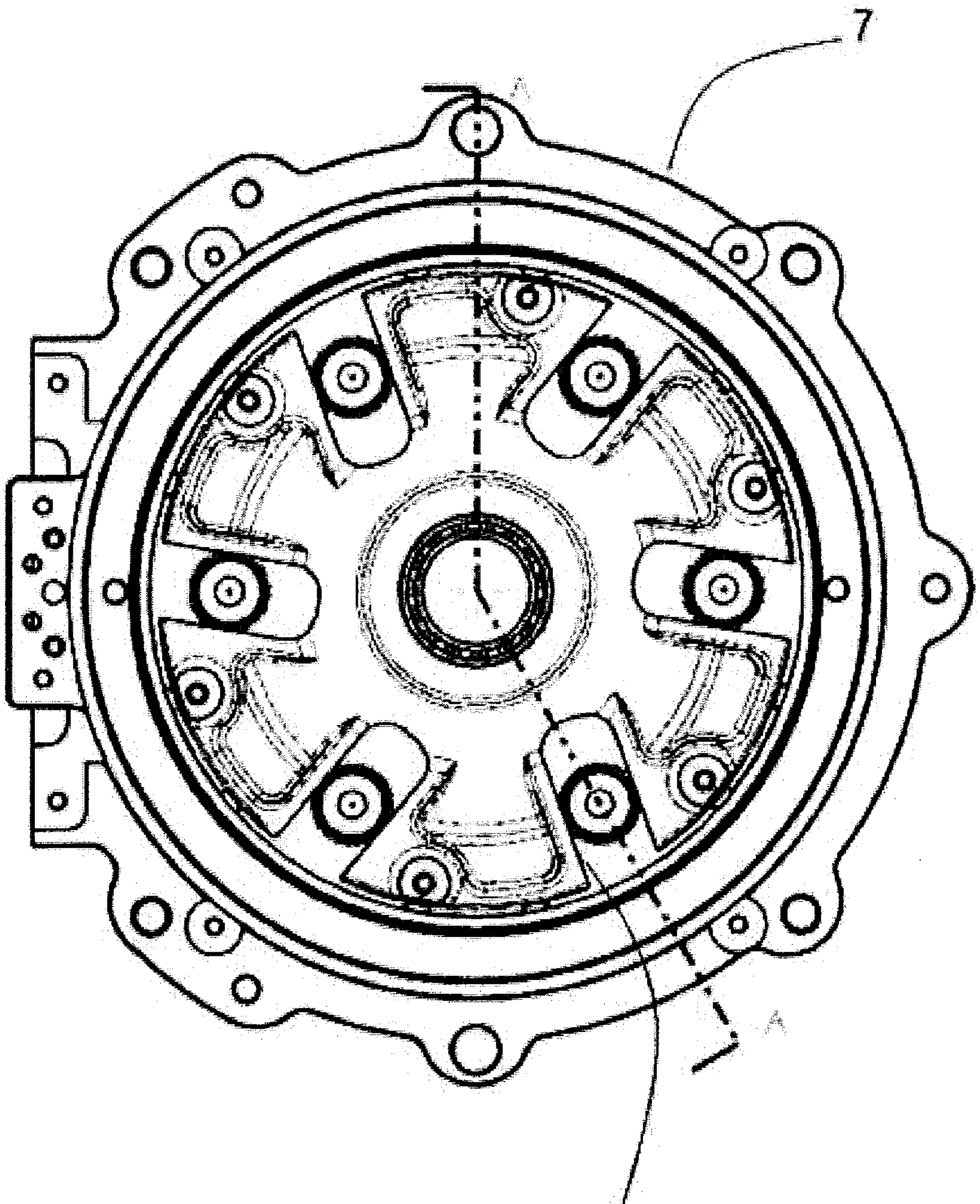
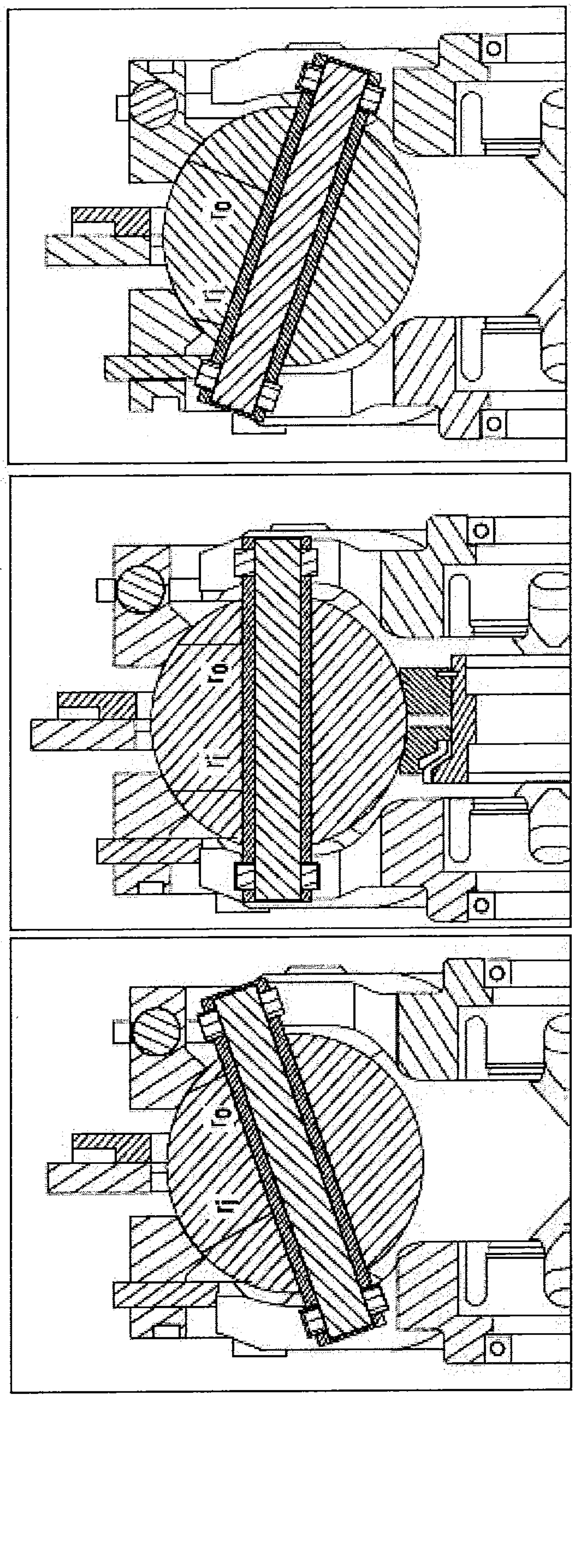


Figure 2



$r_i < r_o$
OVERDRIVE

$r_i = r_o$
1:1

$r_i > r_o$
UNDERDRIVE

FIG. 3

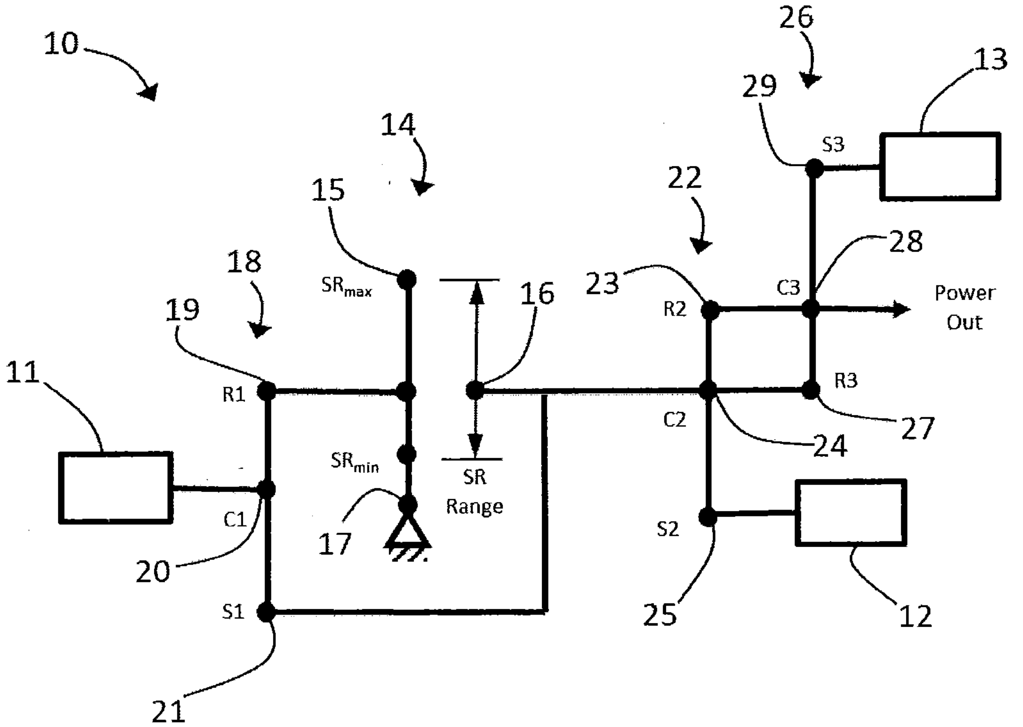


Figure 4

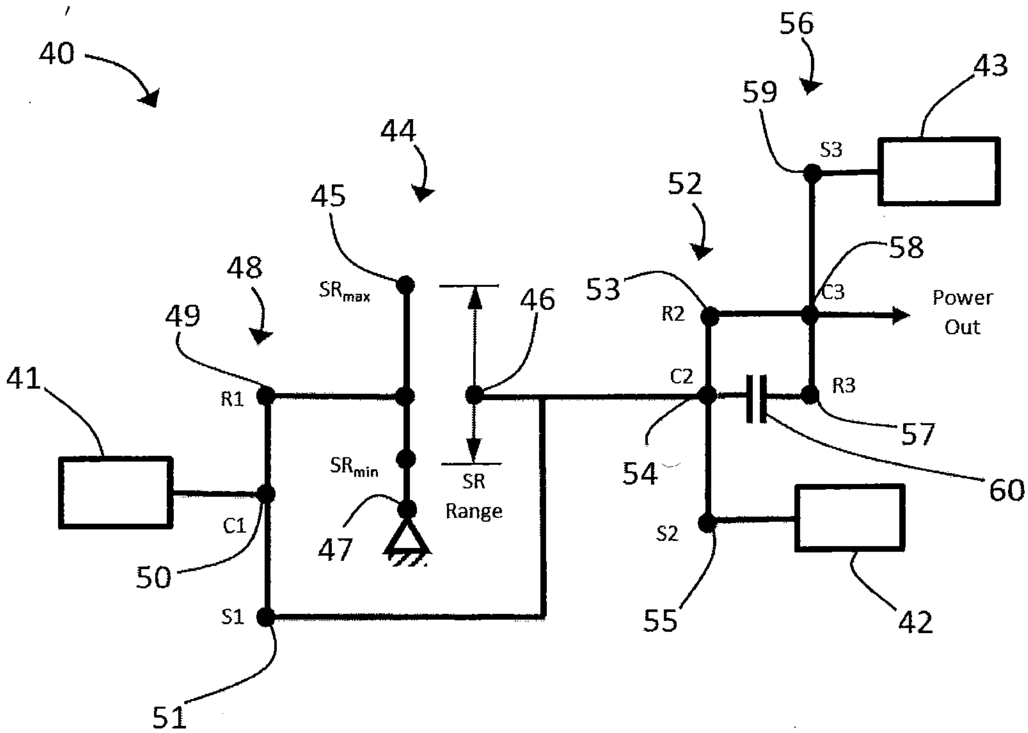


Figure 5

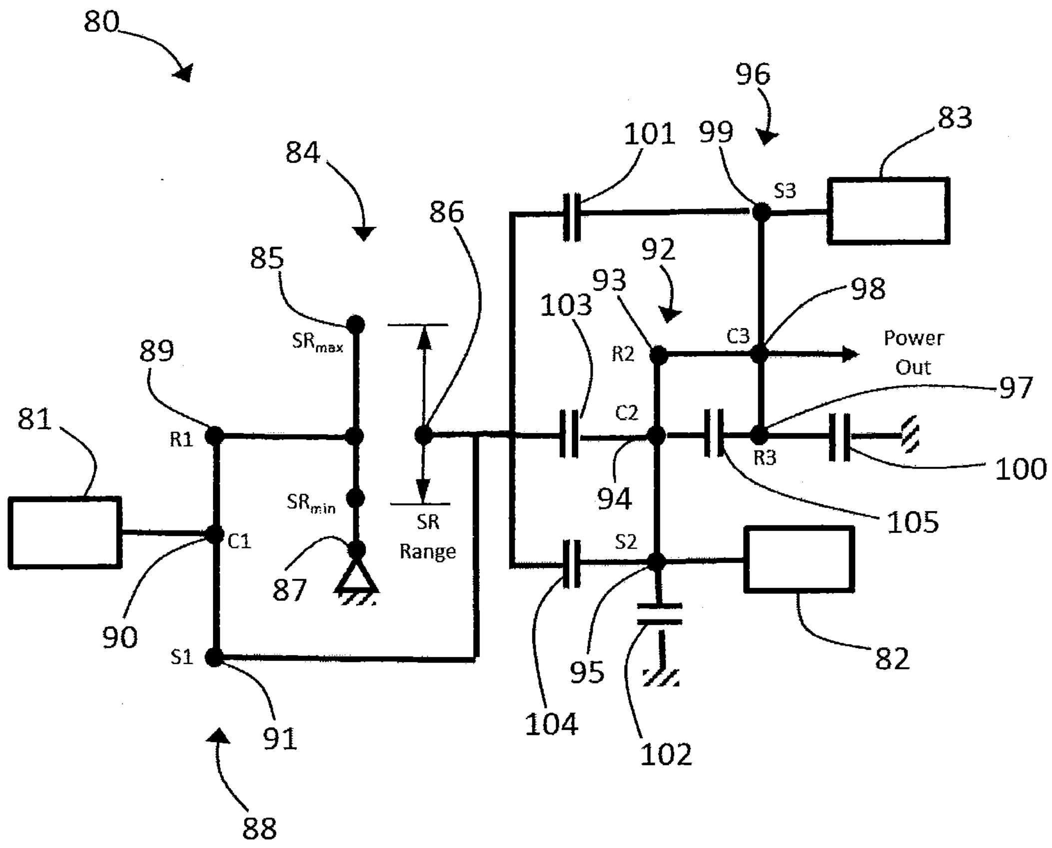


Figure 6

Modes/Clutches	100	101	102	103	104	105
Single Motor Electric Low Mode	X					
Dual Motor Electric Low Mode	X					X
Dual Motor Electric High Mode						X
Input Split Mode	X			X		
Reverse Electric Mode	X					
Compound Split Mode				X		X
First Gear Fixed Mode	X	X				X
Second Gear Fixed Mode		X	X			X
Third Gear Fixed Mode		X		X		X
Fourth Gear Fixed Mode			X	X		X
Reverse Mode	X				X	X

Figure 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/045116

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60K6/365 B60K6/445 B60K6/543 F16H3/72
ADD. F16H15/28 F16H37/02

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)
B60K 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 2017/083522 A1 (DANA LTD [US]) 18 May 2017 (2017-05-18) paragraph [0184]; figure 46	1-7
A	WO 2016/178913 A1 (DANA LTD [US]) 10 November 2016 (2016-11-10) paragraph [0042]; figure 8	1
A	US 2008/076615 A1 (KIM YEON-HO [KR]) 27 March 2008 (2008-03-27) the whole document	1

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

☒ See patent family annex.

* Special categories of cited documents :

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 September 2018	21/09/2018

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	Wurzer, Oliver

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2018/045116

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2017083522 A1	18-05-2017	CN 108463650 A	28-08-2018
		EP 3374667 A1	19-09-2018
		WO 2017083522 A1	18-05-2017
WO 2016178913 A1	10-11-2016	NONE	
US 2008076615 A1	27-03-2008	NONE	