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(71) Applicant: **DANA LIMITED** [US/US]; 3939 Technology Drive, PO Box 1000, Maumee, OH 43537 (US).

(72) Inventors: **BOLLE, Korneel**; Keviestraat 4, 9000 Gent (BE). **DAVID, Jeffrey, M.**; 1808 Spiderlily View, Cedar Park, TX (US). **JANSSENS, Jerome**; Vieux Chemin de Hal 29, 1440 Braine-le-Chateau (BE). **MCINDOE, Gordon M.**; 15304 Randolph Street, Volente, TX 78641 (US). **MCLEMORE, T., Neil**; 613 Garner Park Drive, Georgetown, TX 78628 (US). **MILLER, Travis, J.**; 2930 Grand Oaks Loop #2002, Cedar Park, TX 78613 (US). **PETERS, Sebastian J.**; 610 Wildbriar Ct., Cedar Park, TX 78613 (US). **VYNCKE, Thomas, J.**; Bulkenhof 4, 9800 Deinze (BE).

(74) Agent: **EVANS, Stephen** et al.; MARSHALL & MELHORN, LLC, Four SeaGate - 8th Floor, Toledo, OH 43604 (US).

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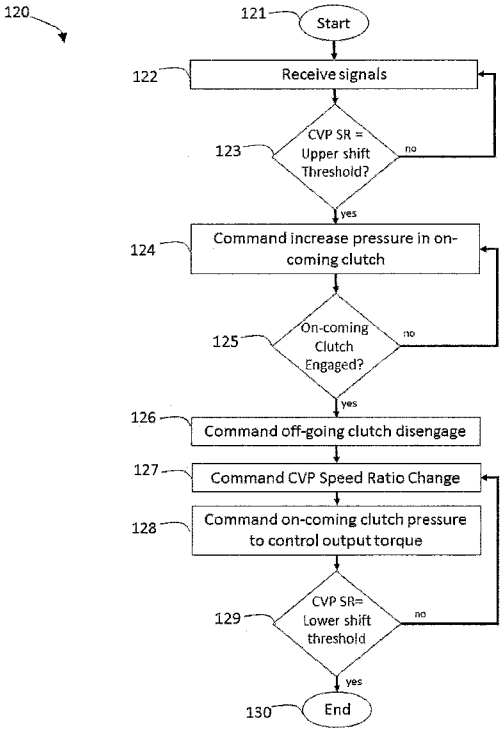


Figure 8

(57) Abstract: Provided herein is a control system for a multiple-mode continuously variable transmission having a ball planetary variator. The control system has a transmission control module configured to receive a plurality of electronic input signals, and to determine a mode of operation from a plurality of control ranges based at least in part on the plurality of electronic input signals. The control system implements a method for controlling a clutch-to-clutch shift of a continuously variable drive (CVD) having a ball-planetary variator (CVP), wherein the CVP is operably coupled to a multiple speed gear box having a first clutch corresponding to a first selectable operating mode and a second clutch corresponding to a second selectable operating mode.

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MULTI-MODE NON-SYNCHRONOUS MODE SHIFTING METHODS FOR A BALL-TYPE PLANETARY TRANSMISSION

RELATED APPLICATIONS

The present application claims the benefit of U.S. Provisional Application No. 62/444,015 filed on January 9, 2017 and U.S. Provisional Application No. 62/450,355 filed on January 25, 2017, which are incorporated herein by reference in their entirety.

BACKGROUND

Continuously variable transmissions (CVT) and transmissions that are substantially continuously variable are increasingly gaining acceptance in various applications. The process of controlling the ratio provided by the CVT is complicated by the continuously variable or minute gradations in ratio presented by the CVT. Furthermore, the range of ratios that are available to be implemented in a CVT are not sufficient for some applications. A transmission is capable of implementing a combination of a CVT with one or more additional CVT stages, one or more fixed ratio range splitters, or some combination thereof in order to extend the range of available ratios. The combination of a CVT with one or more additional stages further complicates the ratio control process, as the transmission will have multiple configurations that achieve the same final drive ratio.

The different transmission configurations could for example, multiply input torque across the different transmission stages in different manners to achieve the same final drive ratio. However, some configurations provide more flexibility or better efficiency than other configurations providing the same final drive ratio.

SUMMARY

A method for controlling a clutch-to-clutch shift of a continuously variable drive (CVD) having a ball-planetary variator (CVP) provided with a ball in contact with a first traction ring assembly, a second traction ring assembly, a first sun member, and a second sun member, wherein the CVP is operably coupled to a multiple speed gear box having a first clutch corresponding to a first selectable operating mode and a second clutch corresponding to a second selectable operating mode, the method including the steps of: receiving a plurality of input signals indicative of a CVP speed ratio, a first clutch pressure, a second clutch pressure, and a CVD output torque; commanding an increase in pressure to the second clutch; commanding a decrease in pressure to the first clutch to disengage the first clutch; commanding a change in the CVP speed ratio; controlling the pressure of the second clutch to deliver a CVD output torque

within a range during the change in the CVP speed ratio; and commanding an increase in the pressure to the second clutch to engage the second clutch.

A method for controlling a continuously variable drive (CVD) having a ball-planetary variator (CVP) provided with a ball in contact with a first traction ring assembly, a second traction ring assembly, a first sun member, and a second sun member, wherein the CVP is operably coupled to a multiple speed gear box having a first clutch corresponding to a first selectable operating mode and a second clutch corresponding to a second selectable operating mode, the method including the steps of: receiving a plurality of input signals indicative of a CVP speed ratio, a first clutch pressure, a second clutch pressure, and a CVD output torque; evaluating the CVP speed ratio compared to an upper shift threshold; commanding an increase in the second clutch pressure to engaged the second clutch based on the evaluation of the CVP speed ratio to the upper shift threshold; commanding a decrease in the first clutch pressure to disengage the first clutch; commanding a change in the CVP speed ratio; commanding the second clutch pressure to control the CVD output torque within a range during the change in the CVP speed ratio; evaluating the CVP speed ratio compared to a lower shift threshold; and commanding a change in second clutch pressure to engage the second clutch based on the evaluation of the CVP speed ratio to the lower shift threshold.

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 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 devices 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 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 block diagram schematic of a vehicle control system.

Figure 5 is a schematic diagram of an exemplary continuously variable drive controllable by the vehicle control system of Figure 4.

Figure 6 is a table depicting the operating modes of the continuously variable drive of Figure 5.

Figure 7 is a graph depicting a relationship between the overall ratio of the continuously variable drive and the variator ratio for two modes of operation.

Figure 8 is a flow chart depicting a mode shift process implementable in the vehicle control system of Figure 4.

Figure 9 is a flow chart depicting another mode shift process implementable in the vehicle control system of Figure 4.

Figure 10 is a graph of clutch pressure, variator (CVP) ratio and torque versus time during a non-synchronous upshift using the mode shift process of Figure 8 and/or Figure 9.

Figure 11 is a flow chart depicting yet another mode shift process that is implementable in the vehicle control system of Figure 4.

Figure 12 is a graph of clutch pressure, variator (CVP) ratio and torque versus time during a non-synchronous upshift using the mode shift process of Figure 11.

Figure 13 is a graph of clutch pressure, variator (CVP) ratio and torque versus time during a non-synchronous downshift using the mode shift process of Figure 8 and/or Figure 9.

Figure 14 is a flow chart depicting a downshift process implementable in the vehicle control system of Figure 4.

Figure 15 is a flow chart depicting a braking downshift process implementable in the downshift process of Figure 14.

Figure 16 is a flow chart depicting another braking downshift process implementable in the downshift process of Figure 14.

Figure 17 is a flow chart depicting a torque control process implementable in the downshift process of Figure 14.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An electronic controller is described herein that enables electronic control over a variable ratio transmission having a continuously variable ratio portion, such as a Continuously Variable Transmission (CVT), Infinitely Variable Transmission (IVT), or variator. The electronic controller can configured to receive input signals indicative of parameters associated with an engine coupled to the transmission. The parameters could include throttle position sensor values, accelerator pedal position sensor values, vehicle speed, gear selector position, user-selectable mode configurations, and the like, or some combination thereof. The electronic controller can also receive one or more control inputs. The electronic controller can determine an active range and an active variator mode based on the input signals and control inputs. The electronic

controller can control a final drive ratio of the variable ratio transmission by controlling one or more electronic actuators and/or solenoids that control the ratios of one or more portions of the variable ratio transmission.

The electronic controller described herein is described in the context of a continuous variable transmission, such as the continuous variable transmission of the type described in U.S. Patent Application Number 14/425,842, entitled "3-Mode Front Wheel Drive And Rear Wheel Drive Continuously Variable Planetary Transmission" and, U.S. Patent Application Number 15/572,288 entitled "Control Method of Synchronous Shifting of a Multi-Range Transmission Comprising a Continuously Variable Planetary Mechanism", each assigned to the assignee of the present application and hereby incorporated by reference herein in its entirety. However, the electronic controller is not limited to controlling a particular type of transmission but rather, is optionally configured to control any of several types of variable ratio transmissions.

Provided herein are configurations of CVTs based on a ball-type variator, 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) traction ring assembly 2 and output (second) traction ring assembly 3, and an idler (sun) assembly 4 as shown on **FIG. 1**. In some embodiments, the output traction ring assembly 3 includes an axial force generator mechanism. The balls are mounted on tiltable axles 5, themselves held in a carrier (stator, cage) assembly having a first carrier member 6 operably coupled to a second carrier member 7. The first carrier member 6 rotates with respect to the second carrier member 7, and vice versa. In some embodiments, the first carrier member 6 is 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 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 adjustable to achieve a desired ratio of input speed to output speed during operation of the CVT. In some embodiments, adjustment of the axles 5 involves control of the position of the first and second carrier members to impart a tilting of the axles 5 and thereby adjusts the speed ratio of the variator. Other types of ball CVTs also exist, like the one produced by Milner, but are slightly different.

The working principle of such a CVP of FIG. 1 is shown on **FIG. 3**. The CVP itself works with a traction fluid. The lubricant between the ball and the conical rings acts as a solid at

high pressure, transferring the power from the input ring, through the balls, to the output ring. By tilting the balls' axes, the ratio is changed between input and output. When the axis is horizontal, the ratio is one, as illustrated in **FIG. 3,** when the axis is tilted, the distance between the axis and the contact point change, modifying the overall ratio. All the balls' axes are tilted at the same time with a mechanism included in the carrier and/or idler. Embodiments disclosed herein are related to the control of a variator and/or a CVT using generally spherical planets each having a tiltable axis of rotation that is adjustable 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 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.

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

For description purposes, the term "radial", as used herein indicates a direction or position that is perpendicular relative to a longitudinal axis of a transmission or variator. The term "axial" as used herein refers to a direction or position along an axis that is parallel to a main or longitudinal axis of a transmission or variator.

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 herein, generally, these are 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

forces that would be available at the interfaces of the contacting components and is a measure of the maximum available drive torque. 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 could operate in both tractive and frictional applications. As a general matter, the traction coefficient μ is a function of the traction fluid properties, the normal force at the contact area, and the velocity of the traction fluid in the contact area, among other things. For a given traction fluid, the traction coefficient μ increases with increasing relative velocities of components, until the traction coefficient μ reaches a maximum capacity after which the traction coefficient μ decays. The condition of exceeding the maximum capacity of the traction fluid is often referred to as "gross slip condition". Traction fluid is also influenced by entrainment speed of the fluid and temperature at the contact patch, for example, the traction coefficient is generally highest near zero speed and decays as a weak function of speed. The traction coefficient often improves with increasing temperature until a point at which the traction coefficient rapidly degrades.

As used herein, "creep", "ratio droop", 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. In traction drives, the transfer of power from a driving element to a driven element via a traction interface requires creep. Usually, creep in the direction of power transfer, is referred to as "creep in the rolling direction." Sometimes the driving and driven elements experience creep in a direction orthogonal to the power transfer direction, in such a case this component of creep is referred to as "transverse creep."

Those of skill will recognize that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein, including with reference to the transmission control system described herein, for example, can implemented as electronic hardware, software stored on a computer readable medium and executable by a processor, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described herein generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans could implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present embodiments. For example, various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein can implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a

field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor can a microprocessor, but in the alternative, the processor can any conventional processor, controller, microcontroller, or state machine. A processor could also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. Software associated with such modules could reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM, or any other suitable form of storage medium known in the art. An exemplary storage medium is coupled to the processor such the processor reads information from, and write information to, the storage medium. In the alternative, the storage medium can integral to the processor. The processor and the storage medium could reside in an ASIC. For example, in one embodiment, a controller for use of control of the CVT includes a processor (not shown).

Referring now to **FIG. 4**, in some embodiments, a vehicle control system 100 includes an input signal processing module 102, a transmission control module 104 and an output signal processing module 106. The input signal processing module 102 is configured to receive a number of electronic signals from sensors provided on the vehicle and/or transmission. The sensors optionally include temperature sensors, speed sensors, position sensors, among others. In some embodiments, the signal processing module 102 optionally includes various sub-modules to perform routines such as signal acquisition, signal arbitration, or other known methods for signal processing. The output signal processing module 106 is optionally configured to electronically communicate to a variety of actuators and sensors. In some embodiments, the output signal processing module 106 is configured to transmit commanded signals to actuators based on target values determined in the transmission control module 104. In some embodiments, the transmission control module 104 includes a variety of sub-modules or sub-routines for controlling continuously variable transmissions of the type discussed here. For example, the transmission control module 104 optionally includes a clutch control sub-module 108 that is programmed to execute control over clutches or similar devices within the transmission. In some embodiments, the clutch control sub-module implements state machine control for the coordination of engagement of clutches or similar devices. The transmission control module 104 optionally includes a CVP control sub-module 110 programmed to execute a variety of measurements and determine target operating conditions of the CVP, for example, of the ball-type continuously variable transmissions discussed herein. It should be noted that the CVP control sub-module 110 optionally incorporates a number of sub-modules for performing

measurements and control of the CVP. In some embodiments, the vehicle control system 100 includes an engine control module 112 configured to receive signals from the input signal processing module 102 and in communication with the output signal processing module 106. The engine control module 112 is configured to communicate with the transmission control module 104.

Referring now to **FIG. 5**, control and diagnostic methods described herein are related to continuously variable drives having a multiple speed gear box operably coupled to a continuously variable planetary device such as those described in reference to FIGS. 1-3, and disclosed in Patent Cooperation Treaty Patent Application No. PCT/US17/026,041, which is hereby incorporated by reference. As an illustrative example of a continuously variable drive, a schematic is depicted in FIG.5. It should be understood that there are a variety of transmission architectures that the control and diagnostic methods described herein are applied to. For example, multiple mode transmissions having two, three, four, or more modes are optionally configured to implement the control processes described herein. In some embodiments, a continuously variable drive (CVD) 175 includes a continuously variable device 176 operably coupled to a multiple speed gear box 177. In some embodiments, the continuously variable device 176 is controlled by the CVP control sub-module 110, and the multiple speed gear box 177 is controlled by the clutch control sub-module 108. It should be appreciated that the transmission control module 104 is optionally adapted to control both the continuously variable device 176 and the multiple speed gear box 177. The CVD 175 includes a first rotatable shaft 178 adapted to couple to a source of rotational power (not shown).

The continuously variable device 176 includes a variator 304 having a first traction ring assembly 305 and a second traction ring assembly 306. In some embodiments, the variator 304 is configured such as the variator depicted in FIGS. 1-3. The continuously variable device 176 includes a first planetary gear set 307 having a first ring gear 308, a first planet carrier 309, and a first sun gear 310. The first planetary gear set 307 is sometimes referred to herein as "the input split planetary gear set" having a ring to sun ratio represented by the term "RTS". The first ring gear 308 is operably coupled to the first traction ring assembly 305. The first planet carrier 309 is operably coupled to the first rotatable shaft 178. The first sun gear 310 is operably coupled to the second traction ring assembly 306. In some embodiments, the first sun gear 310 is operably coupled to a second rotatable shaft 179. The second rotatable shaft 179 is configured to couple to the multiple speed gear box 177. In some embodiments, the multiple speed gear box 177 is provided with a number of clutching devices including a forward mode clutch 180, a reverse mode clutch 181, a first-and-reverse mode clutch 182, a second-and-fourth mode clutch 183, and a third-and-fourth mode clutch 184. In some embodiments, the multiple speed gear box 177

includes a second planetary gear set 185. The second planetary gear set 185 has a second ring gear 186, a second planet carrier 187, and a second sun gear 188. In some embodiments, the second sun gear 188 is coupled to the third-and-fourth mode clutch 184 through a one-way clutch 194. The third-and-fourth mode clutch 184 is operably coupled to the forward mode clutch 180. The second ring gear 186 is coupled to the third-and-fourth mode clutch 184. In some embodiments, the multiple speed gear box 177 includes a third planetary gear set 189 having a third ring gear 190, a third planet carrier 191, and a third sun gear 192. The third sun gear 192 is coupled to the second-and-fourth mode clutch 183 and the reverse clutch 181. The third planet carrier 191 is coupled to the second ring gear 186. The third ring gear 190 is coupled to the second planet carrier 187. The third ring gear 190 and the second planet carrier 187 are adapted to couple to an output drive shaft 193. The output drive shaft 193 is adapted to transmit an output power from the CVD 175 through the range box 177.

Referring now to **FIG. 6**, during operation of the CVD 175 multiple modes of operation are achieved through engagement of the various clutching devices to provide modes corresponding to overlapping ranges of speed and torque. In some embodiments, 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 CVD 175. The table depicted in FIG. 6 lists the modes of operation for the CVD 175 and indicates with an "x" the corresponding clutch engagement or clutch position. For mode 1 operation, the forward mode clutch 180 and the first-and-reverse mode clutch 182 are engaged. For mode 2 operation, the forward mode clutch 180 and the second-and-fourth mode clutch 183 are engaged. For mode 3 operation, the forward mode clutch 180 and the third-and-fourth mode clutch 184 are engaged. For mode 4 operation, the forward mode clutch 180, the second-and-fourth mode clutch 183, and the third-and-fourth mode clutch 184 are engaged. For reverse mode operation, the first-and-reverse mode clutch 182 and the reverse mode clutch 181 are engaged.

Referring now to **FIGS. 7-17**, a typical clutch to clutch power upshift is characterized by having two phases: the torque phase where torque is transferred from one clutch to the other and the inertia phase where any necessary speed change and inertia effects are accomplished. In the described variator equipped transmission, for example CVD 175, an extra degree of freedom is provided by the variator 304 or the continuously variable device 176, and is used to allow a continuous overall transmission ratio (for example the ratio of the CVD 175) during the shift, thus eliminating the stepped change in ratio and associated shift feel of typical automatics. The choice of when exactly to begin moving the variator during the shift is variable and is further described in the following methods.

In some embodiments, a method to determine when to change the ratio of the variator during a mode shift includes initiating a clutch shift as the variator ratio is approaching full overdrive, transferring torque from the off-going to the oncoming clutch by gradually increasing clutch pressure. During this phase the off-going clutch remains synchronized. Therefore, there is still a kinematic link from the variator to the output of the multiple speed gearbox whereby any variator speed ratio change will impact the vehicle acceleration. This prevents decreasing the variator speed ratio during this phase since it will have a direct effect on the transmission output. Additionally, if vehicle acceleration is wanted, the acceleration has to be provided by an increase of the variator speed ratio. The method further includes returning the variator ratio to underdrive during the inertia or synchronizing phase. After the torque phase, the clutch pressure is controlled to shape the desired transmission output torque while the variator speed ratio is reduced to cover the main part of the clutch synchronization. In order to compensate for output torque variations due to torque ratio change in torque phase, the engine provides extra torque during the shift if no loss of acceleration is allowed. This method allows for seamless shifts as long as the engine has sufficient torque capacity left to compensate for the complete transmission torque ratio variation during the torque phase.

In some embodiments, a method to determine when to change the ratio of the variator during a mode shift includes the initiating a clutch shift as the variator ratio is approaching full overdrive and allowing the off-going clutch to slip within a calibrateable range and decoupling the variator from the gear box to provide a degree of freedom on the variator speed ratio. With the variator decoupled, the variator can then immediately be placed into full overdrive. Attention should be paid that the slip speed of the off-going element is not reversed before it is fully released as to avoid damage to the clutch or the variator. The method further includes transferring torque from the off-going to oncoming clutch. If the variator is pushed to full overdrive, the variator is allowed to begin the return to underdrive as long as the off-going slip speed is not reversed. This decreases the necessary engine torque to compensate for the output torque loss. The variator continues to move toward an underdrive ratio (inertia/sync phase). This method provides a range of conditions for which a seamless shift is achievable is increased.

Referring now to **FIG. 7**, an illustrative example of a relationship between an overall transmission speed ratio of the CVD 175, for example, to a speed ratio of the variator (CVP) 304, for example, for a first operating mode 113 and a second operating mode 114. In some embodiments, the CVD 175 includes additional operating modes. For description purposes, methods described herein are applicable to changing between any number of operating modes. As used herein, the terms "upshift" or "upshift event" refer to a change from a lower speed mode

to a higher speed mode; the terms "downshift" or "downshift event" refer to a change from higher speed mode to a lower speed mode.

Moving now to **FIG. 8**, in some embodiments, a mode shift process 120 is implemented in the transmission control module 104. The mode shift process 120 starts at a start state 121 and proceeds to a block 122 where a number of signals are received. For example, the block 122 receives a CVP speed ratio, a first clutch pressure, a second clutch pressure, an engine torque, a first clutch slip speed, a second clutch slip speed, and a transmission speed ratio, among others. The mode shift process 120 proceeds to a first evaluation block 123 where the CVP speed ratio is compared to an upper shift threshold parameter. In some embodiments, the upper shift threshold parameter is a calibrateable parameter stored in memory and is indicative of a CVP speed ratio at which a shift to another operating mode is desirable. In some embodiments, the upper shift threshold parameter is stored in a variety of look-up tables corresponding to upshift and downshift conditions. If the first evaluation block 123 returns a false result, indicating that the CVP speed ratio is not at the upper shift threshold, then the mode shift process 120 proceeds back to the block 122.

If the first evaluation block 123 returns a true result, indicating that the CVP speed ratio is at the upper shift threshold, then the mode shift process 120 proceeds to a block 124. The mode shift process 120 commands an increase in pressure for the on-coming clutch at the block 124. As used herein, the term "on-coming clutch" refers to a clutch that is presently not engaged for the operating mode of the transmission, and is thereby "on-coming" as it engages for torque transfer. The mode shift process 120 proceeds to a second evaluation block 125 where engagement of the on-coming clutch is assessed. If the second evaluation block 125 returns a false result, indicating that the on-coming clutch is not engaged, then the mode shift process 120 returns to the block 124. If the second evaluation block 125 returns a true result, indicating that the on-coming clutch is engaged, then the mode shift process 120 proceeds to a block 126 where a command is sent to disengage the off-going clutch. In some embodiments, disengagement of the off-going clutch is managed by modulating pressure to the off-going clutch. As used herein, the term "off-going" clutch refers to a clutch that is engaged in the present operating mode and is thereby "off-going" as the operating mode is changed.

The mode shift process 120 proceeds to a block 127 where a command is sent to change the CVP speed ratio. For example, in an upshift from mode 1 to mode 2, the CVP speed ratio is approaching an overdrive condition, therefore the block 127 issues a command to change the CVP speed ratio towards an underdrive condition. For a downshift from mode 2 to mode 1, the CVP speed ratio is approaching an underdrive condition, therefore the block 127 issues a command to change the CVP speed ratio towards an overdrive condition. The mode shift process

120 proceeds to a block 128 where a command is sent to control the on-coming clutch pressure. In some embodiments, the commanded pressure for the on-coming clutch corresponds to control of the output torque of the transmission. In some embodiments, a feedback signal generated from an output speed or a slip speed profile that is indicative of the output torque dip during the shift is used to determine the commanded pressure. The mode shift process 120 proceeds to a third evaluation block 129 where the CVP speed ratio is compared to a lower shift threshold parameter. In some embodiments, the lower shift threshold parameter is a calibrateable parameter stored in memory and is indicative of a CVP speed ratio at which the change in the CVP speed ratio is complete. In some embodiments, the lower shift threshold parameter is indicative of a lower limit of the CVP speed ratio of the on-coming mode. For example, in a shift from mode 1 to mode 2, the lower shift threshold parameter is optionally set as an underdrive condition. In some embodiments, for a downshift from mode 2 to mode 1, the lower shift threshold parameter is an overdrive speed ratio. In some embodiments, the lower shift threshold parameter is stored in a variety of look-up tables corresponding to upshift and downshift conditions. If the third evaluation block 129 returns a false result, the mode-shift process 120 returns to the block 127. If the third evaluation block 129 returns a true result, the mode-shift process 120 proceeds to an end state 130. Thereafter, the transmission controller 104 is optionally configured to command pressure to the on-coming clutch to smoothly synchronize the clutch.

Referring now to **FIG. 9**, in some embodiments, a mode shift process 140 is implemented in the transmission control module 104. The mode shift process 140 starts at a start state 141 and proceeds to a block 142 where a number of signals are received. For example, the block 142 receives a CVP speed ratio, a first clutch pressure, a second clutch pressure, an engine torque, and output torque, and a transmission speed ratio, among others. The mode shift process 140 proceeds to a first evaluation block 143 where the CVP speed ratio is compared to an upper shift threshold parameter. In some embodiments, the upper shift threshold parameter is a calibrateable parameter stored in memory and is indicative of a CVP speed ratio at which a shift to another operating mode is desirable. In some embodiments, the upper shift threshold parameter is stored in a variety of look-up tables corresponding to upshift and downshift conditions. It should be appreciated that the first evaluation block 143 is optionally configured to evaluate a lower shift threshold parameter for downshift events. For description purposes, the mode shift process 140 is depicted for an upshift, though it is understood that the mode shift process 140 can be configured for a downshift. If the first evaluation block 143 returns a false result, indicating that the CVP speed ratio is not at the upper shift threshold, then the mode shift process 140 proceeds back to the block 142. If the first evaluation block 143 returns a true result, indicating that the

CVP speed ratio is at the upper shift threshold, then the mode shift process 140 proceeds to a block 144. The mode shift process 140 commands an increase in pressure for the on-coming clutch at the block 144. The mode shift process 140 proceeds to a second evaluation block 145 where the output torque is evaluated to determine if the output torque is within a calibrateable range. If the second evaluation block 145 returns a false result indicating that the output torque is not within the calibrateable range, the mode shift process 140 proceeds to the block 146 where a command is sent to change the engine torque. If the second evaluation block 145 returns a true result indicating that the output torque is within the calibrateable range, the mode shift process 140 proceeds to a third evaluation block 147 where engagement of the on-coming clutch is assessed. If the third evaluation block 147 returns a false result, indicating that the on-coming clutch is not engaged, then the mode shift process 140 returns to the block 144. If the third evaluation block 147 returns a true result, indicating that the on-coming clutch is engaged, then the mode shift process 140 proceeds to a block 148 where a command is sent to disengage the off-going clutch.

The mode shift process 140 proceeds to a block 149 where a command is sent to change the CVP speed ratio. For example, in an upshift from mode 1 to mode 2, the CVP speed ratio is approaching an overdrive condition, therefore the block 149 issues a command to change the CVP speed ratio towards an underdrive condition. For a downshift from mode 2 to mode 1, the CVP speed ratio is approaching an underdrive condition, therefore the block 149 issues a command to change the CVP speed ratio towards an overdrive condition. The mode shift process 140 proceeds to a block 150 where a command is sent to control the on-coming clutch pressure. In some embodiments, the commanded pressure for the on-coming clutch corresponds to control of the output torque of the transmission. The mode shift process 140 proceeds to a fourth evaluation block 151 where the output torque of the transmission is compared to a calibrateable range indicative of a desirable vehicle performance criterion. For example, if it is desirable to have a smooth and imperceptible shift between a first and second operating mode, the calibrateable range is small. In some embodiments, the calibrateable range is in the range of 1% to 5% of the desired output torque and subject to experimentation for vehicle implementation.

It should be noted that math-based output torque dip estimation can be used to generate open loop control tables that define the magnitude of the engine torque compensation request, for example commanded engine torque during the mode shift, based on specific shift conditions, and, optionally the engine torque compensation tables are optionally configured to be adaptive based on a feedback signal generated from the transmission output speed signal or slip speed profile that is indicative of output torque dip during shift. In other embodiments, an output torque sensor or actuator force sensor indicative of output torque is used as a closed loop device.

If the fourth evaluation block 151 returns a false result, the mode shift process 140 proceeds to a block 152 where a command to change the engine torque is issued. If the third evaluation block 151 returns a positive result, indicating that the output torque is within range, the mode shift process proceeds to a fifth evaluation block 153. The fifth evaluation block 153 is where the CVP speed ratio is compared to a lower shift threshold parameter. In some embodiments, the lower shift threshold parameter is a calibrateable parameter stored in memory and is indicative of a CVP speed ratio at which the change in the CVP speed ratio is complete. In some embodiments, the lower shift threshold parameter is indicative of a lower limit of the CVP speed ratio of the on-coming mode. For example, in a shift from mode 1 to mode 2, the lower shift threshold parameter is optionally set as an underdrive speed ratio. In some embodiments, for a downshift from mode 2 to mode 1, the lower shift threshold parameter is an overdrive speed ratio. In some embodiments, the lower shift threshold parameter is stored in a variety of look-up tables corresponding to upshift and downshift conditions. If the fifth evaluation block 153 returns a false result, the mode-shift process 140 returns to the block 149. If the fifth evaluation block 153 returns a true result, the mode-shift process 140 proceeds to an end state 154. Thereafter, the transmission controller 104 is optionally configured to command pressure to the on-coming clutch to smoothly synchronize the on-coming clutch.

Referring now to **FIG. 10**, in some embodiments, a shift from a first operating mode to a second operating mode using the mode shift process 120 and/or the mode shift process 140 is characterized as having a torque phase 131 and an inertia phase 132. As depicted in the graph of Figure 10, a first clutch pressure 133, indicative of the operating pressure of off-going clutch is shown with respect to time on the y-axis of the graph. Also depicted in the graph of Figure 10 is a second clutch pressure 134 indicative of the operating pressure of the on-coming clutch, a CVP speed ratio 135, a transmission output torque 136, and a transmission input torque 137. It should be appreciated that the off-going clutch, depicted by the first clutch pressure 133, is not allowed to slip during the torque phase of the mode shift process. For an illustrative upshift, the CVP speed ratio 135 is commanded toward underdrive during the inertia phase 132.

Moving now to **FIG. 11**, in some embodiments, a mode shift process 160 is implemented in the transmission control module 104. The mode shift process 160 starts at a start state 161 and proceeds to a block 162 where a number of signals are received. For example, the block 162 receives a CVP speed ratio, a first clutch pressure, a second clutch pressure, an engine torque, and a transmission speed ratio, among others. The mode shift process 160 proceeds to a first evaluation block 163 where the CVP speed ratio is compared to an upper shift threshold parameter. In some embodiments, the upper shift threshold parameter is a calibrateable parameter stored in memory and is indicative of a CVP speed ratio at which a shift to another

operating mode is desirable. In some embodiments, the upper shift threshold parameter is stored in a variety of look-up tables corresponding to upshift and downshift conditions. If the first evaluation block 163 returns a false result, indicating that the CVP speed ratio is not at the upper shift threshold, then the mode shift process 160 proceeds back to the block 162. If the first evaluation block 163 returns a true result, indicating that the CVP speed ratio is at the upper shift threshold, then the mode shift process 160 proceeds to a block 164. The mode shift process 160 commands an increase in pressure for the on-coming clutch at the block 164. The mode shift process 160 proceeds to a block 165 where a command to decrease the pressure in the off-going clutch is issued. The command to decrease the pressure in the off-going clutch results in slipping of the off-going clutch. The mode shift process 160 proceeds to a block 166 where a command to change the CVP speed ratio is issued. For example, in an upshift from mode 1 to mode 2, the CVP speed ratio is approaching an overdrive condition, therefore the block 166 issues a command to change the CVP speed ratio towards an overdrive condition while the off-going clutch is slipping and pressure is increasing in the on-coming clutch. For a downshift from mode 2 to mode 1, the CVP speed ratio is approaching an underdrive condition, therefore the block 166 issues a command to change the CVP speed ratio towards an underdrive condition while the off-going clutch is slipping and pressure is increasing in the on-coming clutch.

The mode shift process 160 proceeds to a second evaluation block 167 where engagement of the on-coming clutch is assessed. If the second evaluation block 167 returns a false result, indicating that the on-coming clutch is not engaged, then the mode shift process 160 returns to the block 164. If the second evaluation block 167 returns a true result, indicating that the on-coming clutch is engaged, then the mode shift process 160 proceeds to a block 168 where a command is sent to disengage the off-going clutch. The mode shift process 160 proceeds to a block 169 where a command is sent to change the CVP speed ratio. For example, in an upshift from mode 1 to mode 2, the CVP speed ratio is approaching an overdrive condition, therefore the block 169 issues a command to change the CVP speed ratio towards an underdrive condition. For a downshift from mode 2 to mode 1, the CVP speed ratio is approaching an underdrive condition, therefore the block 169 issues a command to change the CVP speed ratio towards an overdrive condition. The mode shift process 160 proceeds to a block 170 where a command is sent to control the on-coming clutch pressure. In some embodiments, the commanded pressure for the on-coming clutch corresponds to control of the output torque of the transmission. In some embodiments, the block 170 is configured to issue engine torque commands to control the transmission output torque during the mode shift. The mode shift process 160 proceeds to a third evaluation block 171 where the CVP speed ratio is compared to a lower shift threshold parameter. In some embodiments, the lower shift threshold parameter is a calibrateable

parameter stored in memory and is indicative of a CVP speed ratio at which the change in the CVP speed ratio is complete. In some embodiments, the lower shift threshold parameter is indicative of a lower limit of the CVP speed ratio of the on-coming mode. For example, in a shift from mode 1 to mode 2, the lower shift threshold parameter is optionally set as an underdrive speed ratio. In some embodiments, for a downshift from mode 2 to mode 1, the lower shift threshold parameter is an overdrive speed ratio. In some embodiments, the lower shift threshold parameter is stored in a variety of look-up tables corresponding to upshift and downshift conditions. If the third evaluation block 171 returns a false result, the mode-shift process 160 returns to the block 169. If the third evaluation block 171 returns a true result, the mode-shift process 160 proceeds to an end state 172. Thereafter, the transmission controller 104 is optionally configured to command pressure to the on-coming clutch to smoothly synchronize the on-coming clutch.

Referring now to **FIG. 12**, in some embodiments, a shift from a first operating mode to a second operating mode using the mode shift process 160 is characterized as having a torque phase 153 and an inertia phase 154. As depicted in the graph of Figure 12, a first clutch pressure 155, indicative of the operating pressure of off-going clutch is shown with respect to time on the y-axis of the graph. Also depicted in the graph of Figure 12 is a second clutch pressure 156 indicative of the operating pressure of the on-coming clutch, a CVP speed ratio 157, a transmission output torque 158, and a transmission input torque 159. It should be appreciated that the off-going clutch, depicted by the first clutch pressure 155, is allowed to slip during the torque phase of the mode shift process 160. For an illustrative upshift, the CVP speed ratio 157 is commanded toward underdrive during the inertia phase 154.

Referring now to **FIG. 13**, and returning to FIGS. 8 and 9, the mode shift process 120 and the mode shift process 140 are depicted in a power off downshift event in the graph of FIG. 13. In some embodiments, a shift from a first operating mode to a second operating mode using the mode shift process 120 or the mode shift process 140 is characterized as having a torque phase 200 and an inertia phase 201. As depicted in the graph of Figure 13, a first clutch pressure 202, indicative of the operating pressure of off-going clutch is shown with respect to time on the y-axis of the graph. depicted in the graph of Figure 13 is a second clutch pressure 203 indicative of the operating pressure of the on-coming clutch, a CVP speed ratio 204, a transmission input torque 205, and a transmission output torque 206. Note that the torque scale during mode shift is negative in Figure 13. It should be appreciated that the mode shift process 160 is similarly applicable to a downshift event. For example, the downshift event depicted in FIG. 13 generally illustrates that CVP speed ratio 204 approaching a full underdrive condition and is changed

toward an overdrive condition during the inertia phase 201, corresponding to a higher mode clutch releasing while a lower mode clutch engages.

Referring now to **FIG. 14,** in some embodiments, a downshift control process 210 is implemented in the transmission control module 104. The downshift control process 210 begins at a start state 211 and proceeds to a block 212 where a number of signals are received. For example, the block 212 receives a CVP speed ratio, a first clutch pressure, a second clutch pressure, an engine torque, and output torque, and a transmission speed ratio, among others. The downshift process 210 proceeds to a first evaluation block 213 where the CVP speed ratio is compared to a lower shift threshold parameter. In some embodiments, the lower shift threshold parameter is a calibrateable parameter stored in memory and is indicative of a CVP speed ratio at which a shift to another operating mode is desirable. If the first evaluation block 213 returns a false result, indicating that the CVP speed ratio is not at the lower shift threshold, then the downshift process 210 proceeds back to the block 212. If the first evaluation block 213 returns a true result, indicating that the CVP speed ratio is at the lower shift threshold, then the downshift process 210 proceeds to a second evaluation block 214 where a torque direction of the off-going clutch is compared to the torque direction of the on-coming clutch. If the second evaluation block 214 returns a true result indicating that the torque direction of the on-coming clutch is the same as the direction of the off-going clutch, the downshift process 210 proceeds to a block 215. The block 215 is configured to execute a braking downshift process. If the second evaluation block 214 returns a false result indicating that the torque direction of the on-coming clutch is not the same as the torque direction of the off-going clutch, the downshift process 210 proceeds to a block 216 where a command is sent to decrease pressure in the off-going clutch.

The downshift process 210 proceeds to a third evaluation block 217. The third evaluation block 217 evaluates slipping of the off-going clutch. If the third evaluation block 217 returns a false result indicating that the off-going clutch is not slipping, the downshift process 210 returns to the block 216. If the third evaluation block 217 returns a true result indicating that the off-going clutch is slipping, the downshift process 210 proceeds to a block 218. The block 218 is configured to execute an output torque control process. The downshift process 210 proceeds to a fourth evaluation block 219 where a slip sign of the on-coming clutch is evaluated. As used herein, the term "slip sign" indicates the sign, positive or negative, of the slip speed of the clutch. The slip speed of the clutch is the difference between the speed into the clutch and the speed out of the clutch. As used herein, the term "torque direction" is the product of the sign of the speed into the clutch and the sign of the slip speed. If the fourth evaluation block 219 returns a false result indicating that there is no change in the slip sign of the on-coming clutch, the downshift process 210 returns to the block 218. If the fourth evaluation block 219 returns a true result

indicating that there is a change in the slip sign of the on-coming clutch, the downshift process 210 proceeds to a block 220. The block 220 is configured to execute three simultaneous commands: a command to increase pressure in the on-coming clutch, a command to decrease pressure in the off-going clutch, and a command to change the CVP speed ratio. In some embodiments, the block 220 is optionally configured to command the engine torque.

The downshift process 210 proceeds to a fifth evaluation block 221 where engagement of the on-coming clutch is evaluated. If the fifth evaluation block 221 returns a false result indicating that the on-coming clutch is not engaged, the downshift process 210 returns to the block 220. If the fifth evaluation block 221 returns a true result indicating that the on-coming clutch is engaged, the downshift process 210 proceeds to a block 222. The block 222 is configured to command a disengagement of the off-going clutch. The downshift process 210 proceeds to a block 223 where a command is sent to change to the CVP speed ratio. The downshift process 210 proceeds to a block 224 where a command is sent to change pressure in the on-coming clutch and a command is sent to change in engine torque to control output torque. The downshift process 210 proceeds to a sixth evaluation block 225 where the on-coming clutch is evaluated. If the sixth evaluation block 225 returns a false result indicating that the on-coming clutch is not locked, the downshift process 210 returns to the block 223. If the sixth evaluation block 225 returns a true result indicating that the on-coming clutch is locked, the downshift process 210 proceeds to an end state 226.

Referring now to **FIG. 15**, in some embodiments, the braking downshift process 215 begins at a start state 230 and proceeds to a block 231 where a command is sent to increase pressure in the on-coming clutch. The braking downshift process 215 proceeds to a first evaluation block 232 where engagement of the on-coming clutch is evaluated. If the first evaluation block 232 returns a false result indicating that the on-coming clutch is not engaged, the braking downshift process 215 returns to the block 231. If the first evaluation block 232 returns a true result indicating that the on-coming clutch is engaged, the braking downshift process 215 proceeds to a block 233 where a command is send to disengage the off-going clutch. The braking downshift process 215 proceeds to a block 234 where a command is send to change the CVP speed ratio toward an overdrive condition. The braking downshift process 215 proceeds to a block 235 where a command is send to change the pressure in the on-coming clutch to control the output torque. The braking downshift process 215 proceeds to a second evaluation block 236 where the CVP speed ratio is compared to an upper shift threshold. If the second evaluation block 236 returns a false result indicating that the CVP speed ratio is below the upper shift threshold, the braking downshift process 215 returns to the block 234. If the second

evaluation block 236 returns a true result indicating that the CVP speed ratio is at the upper shift threshold, the braking downshift process 215 proceeds to an end state 237.

Referring now to **FIG. 16**, embodiments, the braking downshift process 215 begins at a start state 240 and proceeds to a block 241 where a command is sent to increase pressure in the on-coming clutch. The braking downshift process 215 proceeds to a first evaluation block 242 where engagement of the on-coming clutch is evaluated. If the first evaluation block 242 returns a false result indicating that the on-coming clutch is not engaged, the braking downshift process 215 returns to the block 241. If the first evaluation block 242 returns a true result indicating that the on-coming clutch is engaged, the braking downshift process 215 proceeds to a block 243 where a command is send to disengage the off-going clutch. The braking downshift process 215 proceeds to a block 244 where a command is send to change the CVP speed ratio toward an overdrive condition. The braking downshift process 215 proceeds to a block 245 where a command is send to change the pressure in the on-coming clutch to control the output torque. In some embodiments, the braking downshift process 215 proceeds to a second evaluation block 246 where the output torque is compared to a calibrateable range. If the second evaluation block 246 returns a false result indicating that the output torque is not within the calibrateable range, the braking downshift process 215 proceeds to a block 247 where a command is sent to change the engine torque. If the second evaluation block 246 returns a true result indicating that the output torque is within the calibrateable range, the braking downshift process 215 proceeds to a third evaluation block 248 where the CVP speed ratio is compared to a lower shift threshold. If the third evaluation block 248 returns a false result indicating that the CVP speed ratio is below the lower shift threshold, the braking downshift process 215 returns to the block 244. If the third evaluation block 248 returns a true result indicating that the CVP speed ratio is at the upper shift threshold, the braking downshift process 215 proceeds to an end state 249.

Referring now to **FIG. 17**, in some embodiments, the output torque control process 218 begins at a start state 260 and proceeds to a first evaluation block 261 where a desired kick-down is determined. As used herein the term "kick-down" refers to the condition when there is a sudden increase in output torque demand, for example when the accelerator or throttle pedal is pushed completely to the floor in an instant. As used herein the term "coastdown" refers to the condition when there is a less severe torque demand, for example driving from a flat road up a hill, a downshift to be able to maintain to the same output speed. If the first evaluation block 261 returns a true result indicating that a kick-down is desired, the output torque control process 218 proceeds to a block 262 where a command is sent to decrease the pressure in the off-going clutch. The output torque control process 218 then proceeds to an end state 263. If the first evaluation block 261 returns a false result indicating that a coastdown is desired, the output torque control

process 218 proceeds to a second evaluation block 264 to evaluate available engine torque. If the second evaluation block 264 returns a false result indicating that there is no engine torque available, the output torque control process 218 proceeds to a block 265 configured to issue two simultaneous commands: a command to change the CVP speed ratio towards overdrive and a command to decrease pressure in the off-going clutch. The output torque control process 218 proceeds to the end state 263. If the second evaluation block 264 returns a true result indicating that engine torque is available, the output torque control process 218 proceeds to a block 266. The block 266 is configured to issue simultaneous commands to change the CVP speed ratio toward overdrive and use engine torque to control the output torque. The output torque control process 218 proceeds to an end state 263.

It should be appreciated that, in some embodiments, a change in the CVP speed ratio towards overdrive can be used to prevent engine flare during shift. In some embodiments, integrated powertrain control (for example, using engine torque manipulation) may be used to fill in output torque holes during the shift.

In some embodiments, closed loop output torque disturbance tracking is possible if torque sensor is equipped for production, or used during development and calibration to develop open loop control tables to execute shift if sensor is thrifted. A control actuator for closed loop can be variator ratio and/or slip speed profile of oncoming/off-going clutch.

In some embodiments, the choice of the methods presented herein is variable and is defined uniquely for each mode shift (primarily dependent on elements involved: for example, handoff from grounded element to spinning element, spinning element to spinning element, upshift vs. downshift, etc.)

In some embodiments, a step change in overall ratio during a downshift may be a desired effect. In some embodiments, above a calibrated driver demand threshold, the shift strategy may allow for a simulated stepped gear mode, particularly at wide open throttle (WOT) conditions where there is no torque reserve to allow for engine intervention to fill torque holes.

In other embodiments, when no engine torque compensation is used, the output torque disturbance can be limited by minimizing the torque phase duration and thus modulating the output torque with oncoming pressure faster. This does not significantly change the magnitude of the output torque disturbance but limits the global acceleration loss. The torque phase duration will be mainly constrained by the clutch hydraulics (pressure rise) while the inertia phase will be constrained by the maximum achievable change in variator speed ratio.

In some embodiments, a method to reduce inertia "bump" when ongoing clutch transitions from slow to zero slip: The CVP ratio target for the clutch lockup point should allow a small margin or "safety margin" between the corresponding ratio angle and the ratio angle where

the ratio mechanism is physically limited from further shift. For example, the safety margin is optionally selected to correspond to any mechanical or physical backlash in a shift actuator equipped on the variator or on the shift stop of the variator. When the clutch slip becomes very small, for example, slip less than 1%, the pressure supply to the ratio control valve should be limited to a very small percentage greater than the actual control pressure, for example the ratio control valve supply pressure is set to less than 1% above the actual control pressure. The limiting device should have a bypass or "blow off" function and a definable time response. When the clutch stops slipping, the related "bump" causes the control force to exceed the supply pressure and the drive ratio droops in such a way that the bump is softened. When the shift actuator is not hydraulically activated, the available shift force may be controlled by utilizing a variable force slip clutch such as an electro-magnetic clutch or limiting the available current to an electrically driven actuator.

Further provided herein is a vehicle including a continuously variable drive (CVD) and a controller. The CVD includes a first rotatable shaft forming a main axis operably coupleable to a source of rotational power and a continuously variable planetary (CVP). In some embodiments, the CVP is a ball 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 and wherein the ball variator assembly is coaxial with the main axis. The CVD further includes a CVD input planetary gear set having a ring gear, a planet carrier, and a sun gear, wherein the planet carrier is operably coupled to the first rotatable shaft, the ring gear is coupled to the first traction ring assembly, and the sun gear is coupled to the second traction ring assembly. The CVD further includes a multiple speed gearbox having a plurality of selectable operating modes, wherein the multiple speed gearbox is operably coupled to the second traction ring assembly and the sun gear. The controller is configured to control a CVP speed ratio, the plurality of selectable operating modes, and an output torque of the multiple speed gearbox within a calibrateable range. The control of the plurality of selectable operating modes includes a release of a first selectable operating mode and an engagement of a second selectable operating mode. The controller commands a change in the CVP speed ratio in coordination with the release of a first selectable operating mode and the engagement of the second selectable operating mode that delivers the output torque within the calibrateable range. In some embodiments, the controller is configured to control an upshift from the first selectable operating mode to the second selectable operating mode and commands a release of the first selectable operating mode, a change in the CVP speed ratio towards underdrive, and the engagement of the second selectable operating mode. The command of the engagement of the second selectable operating mode is based at least in part on the output torque. In some embodiments, the

controller is configured to control a downshift from the first selectable operating mode to the second selectable operating mode and commands a release of the first selectable operating mode, a change in the CVP speed ratio towards overdrive, and the engagement of the second selectable operating mode. The command of the engagement of the second selectable operating mode is based at least in part on the output torque. In some embodiments, the controller is further configured to command an engine torque during the upshift to maintain the output torque within the calibrateable range. In some embodiments, the controller is further configured to command an engine torque during the downshift to maintain the output torque within the calibrateable range.

The foregoing description details certain embodiments. It will be appreciated, however, that no matter how detailed the foregoing appears in text, the preferred embodiments are practiced in many ways. As is also stated above, it should be noted that the use of particular terminology when describing certain features or aspects of the preferred embodiments should not be taken to imply that the terminology is being re-defined herein to be restricted to including any specific characteristics of the features or aspects of the preferred embodiments with which that terminology is associated.

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 preferred embodiments described herein can employed in practicing the preferred embodiments. 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.

CLAIMS

WHAT IS CLAIMED IS:

1. A method for controlling a clutch-to-clutch shift of a continuously variable drive (CVD) having a ball-planetary variator (CVP) provided with a ball in contact with a first traction ring assembly, a second traction ring assembly, a first sun member, and a second sun member, wherein the CVP is operably coupled to a multiple speed gear box having a first clutch corresponding to a first selectable operating mode and a second clutch corresponding to a second selectable operating mode, the method comprising the steps of:

receiving a plurality of input signals indicative of a CVP speed ratio, a first clutch pressure, a second clutch pressure, and a CVD output torque;

commanding an increase in pressure to the second clutch;

commanding a decrease in pressure to the first clutch to disengage the first clutch;

commanding a change in the CVP speed ratio;

controlling the pressure of the second clutch to deliver a CVD output torque within a range during the change in the CVP speed ratio; and

commanding an increase in the pressure to the second clutch to engage the second clutch.

2. The method of Claim 1, wherein commanding a decrease in pressure to the first clutch further comprises the step of controlling a slip speed of the first clutch.

3. The method of Claim 1, wherein commanding a change in the CVP speed ratio further comprises commanding a change toward overdrive for a downshift from the first selectable operating mode to the second selectable operating mode.

4. The method of Claim 1, wherein commanding a change in the CVP speed ratio further comprises commanding a change toward underdrive for an upshift from the first selectable operating mode to the second selectable operating mode.

5. The method of Claim 1 further comprising controlling an input torque to the CVD to deliver a CVD output torque within a range during the change in the CVP speed ratio.

6. The method of Claim 5, wherein controlling an input torque further comprising commanding an engine torque.

7. A method for controlling a continuously variable drive (CVD) having a ball-planetary variator (CVP) provided with a ball in contact with a first traction ring assembly, a second traction ring assembly, a first sun member, and a second sun member, wherein the CVP is operably coupled to a multiple speed gear box having a first clutch corresponding to a first selectable operating mode and a second clutch corresponding to a second selectable operating mode, the method comprising the steps of:

receiving a plurality of input signals indicative of a CVP speed ratio, a first clutch pressure, a second clutch pressure, and a CVD output torque;

evaluating the CVP speed ratio compared to an upper shift threshold;

commanding an increase in the second clutch pressure to engaged the second clutch based on the evaluation of the CVP speed ratio to the upper shift threshold;

commanding a decrease in the first clutch pressure to disengage the first clutch;

commanding a change in the CVP speed ratio;

commanding the second clutch pressure to control the CVD output torque within a range during the change in the CVP speed ratio;

evaluating the CVP speed ratio compared to a lower shift threshold; and

commanding a change in second clutch pressure to engage the second clutch based on the evaluation of the CVP speed ratio to the lower shift threshold.

8. The method of Claim 7, further comprising evaluating the CVD output torque compared to a range.

9. The method of Claim 8, further comprising commanding an engine torque to control the CVD output torque within the range based on the evaluation of the CVD output torque.

10. The method of Claim 7, wherein commanding a decrease in the first clutch pressure further comprises controlling the first clutch pressure during the change in the CVP speed ratio.

11. The method of Claim 7, wherein the upper shift threshold is a calibrateable parameter indicative of a CVP speed ratio where a change from a first operating mode to a second operating mode is desired.

12. The method of Claim 7, wherein the lower shift threshold is a calibrateable parameter indicative of a CVP speed ratio where a change from a first selectable operating mode to a second selectable operating mode is complete.

13. The method of Claim 12, wherein the first selectable operating mode corresponds to engagement of the first clutch and disengagement of the second clutch.

14. The method of Claim 12, wherein the first selectable operating mode corresponds to a lower speed range than the second selectable operating mode.

15. The method of Claim 12, wherein the first selectable operating mode corresponds to a higher speed range than the second selectable operating mode.

16. The method of Claim 7, wherein commanding a decrease in the first clutch pressure further comprises controlling slip in the first clutch during the change of the CVP speed ratio.

17. The method of Claim 7, wherein the plurality of data signals further comprise a first clutch slip speed and a second clutch slip speed.

18. The method of Claim 7, wherein commanding the second clutch pressure further comprises monitoring the first clutch slip speed and the second clutch slip speed.

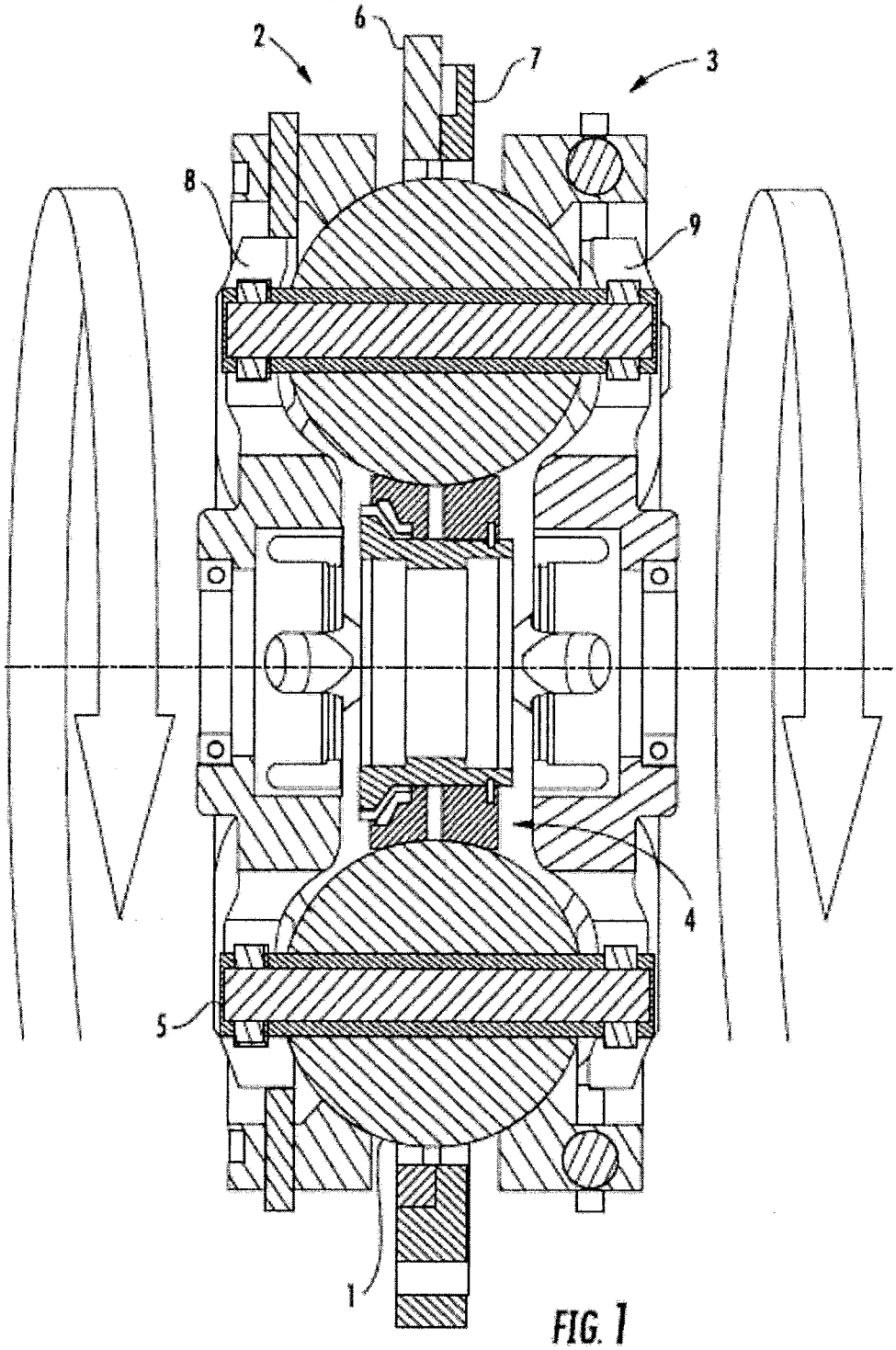


FIG. 1

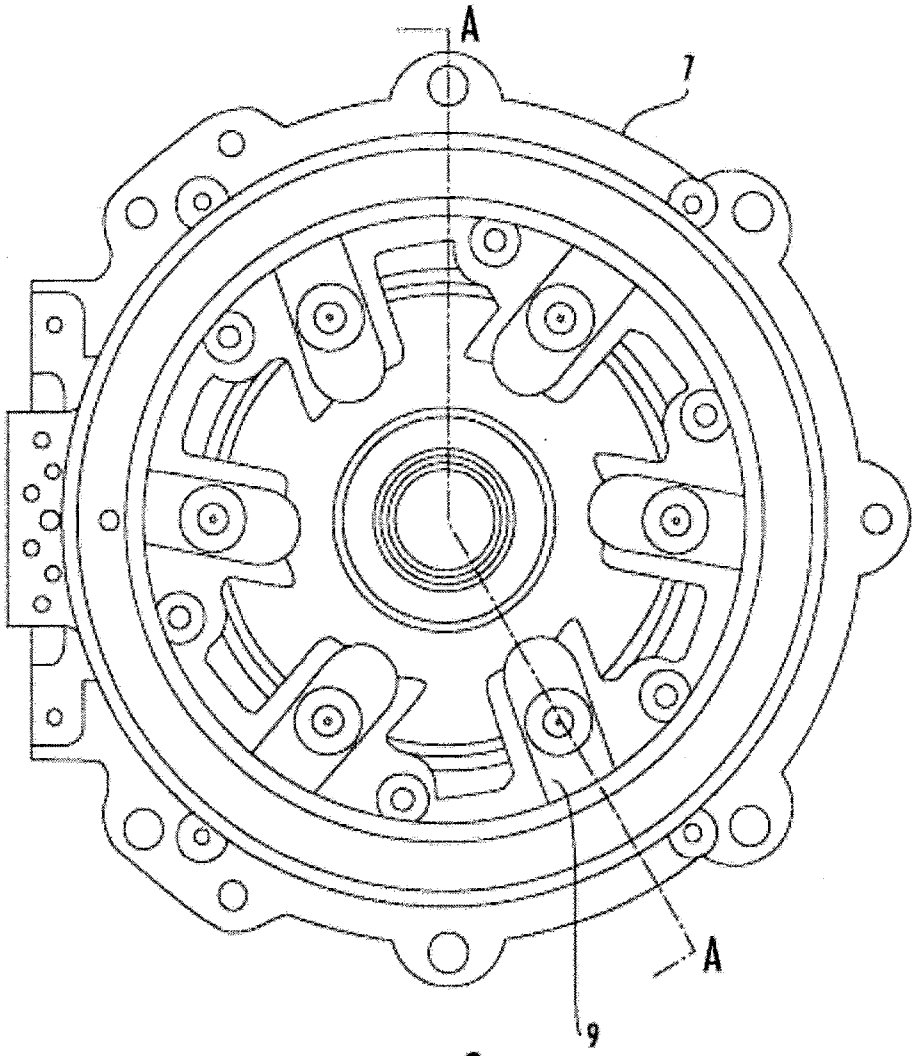


FIG. 2

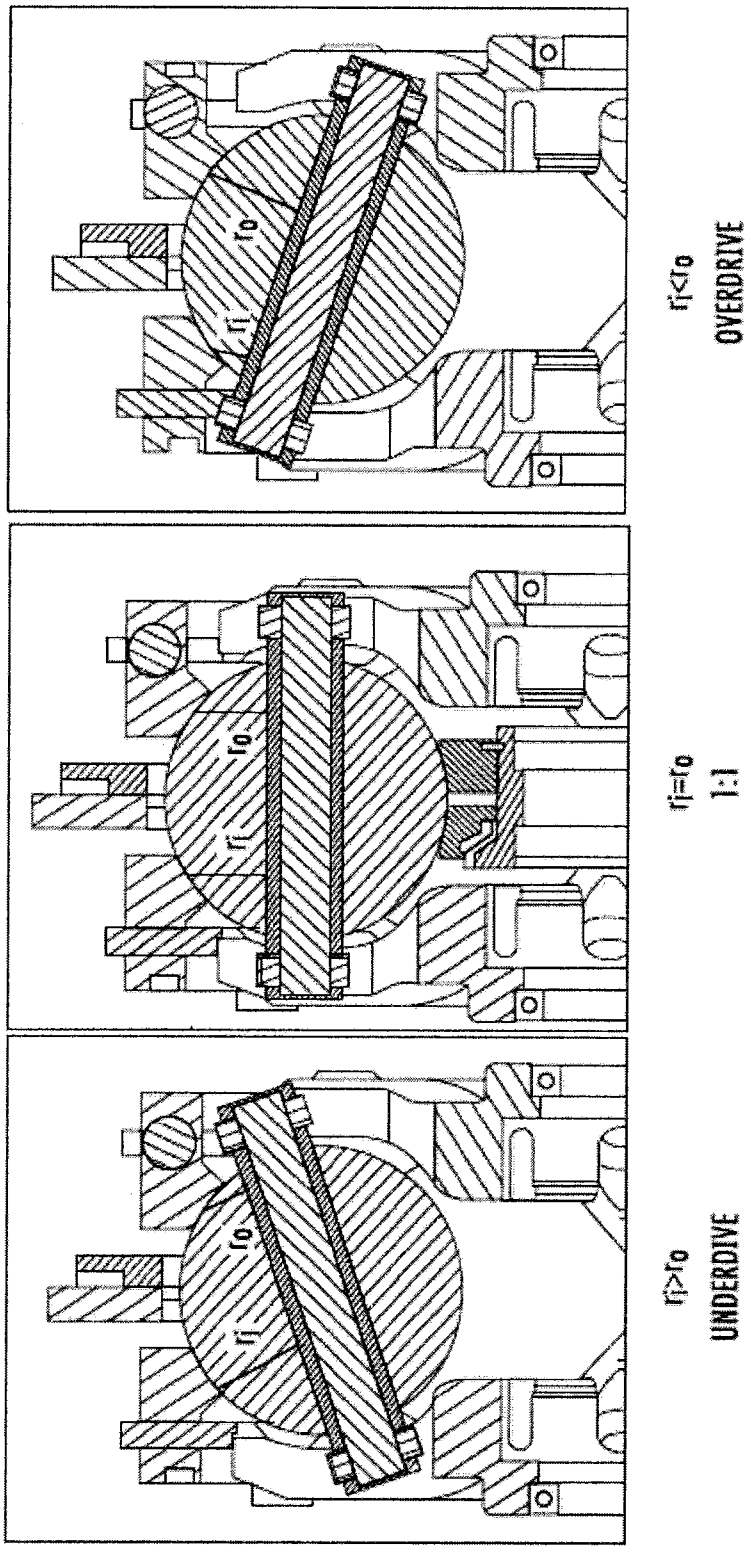


FIG. 3

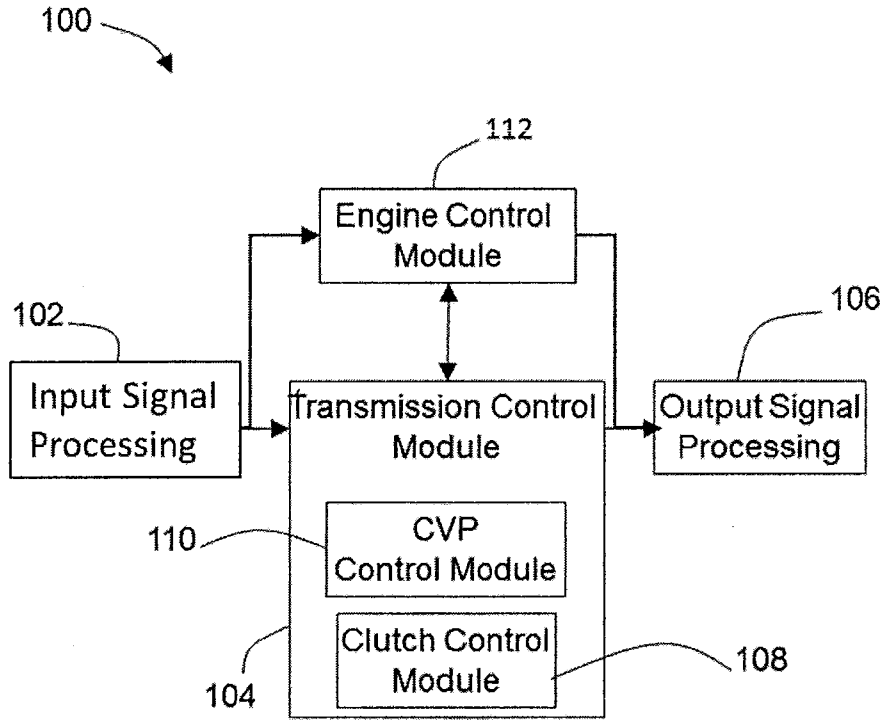


Figure 4

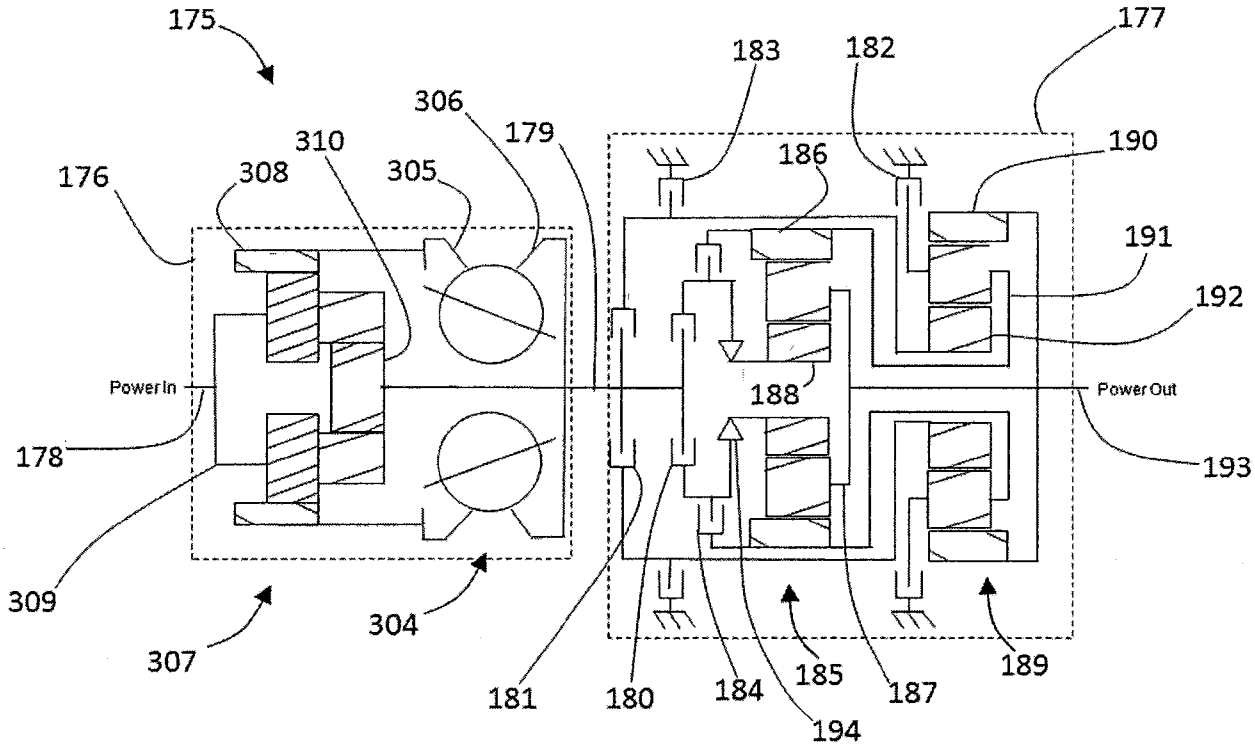


Figure 5

	180	181	182	183	184
Mode 1	X		X		
Mode 2	X			X	
Mode 3	X				X
Mode 4	X			X	X
Reverse		X	X		

Figure 6

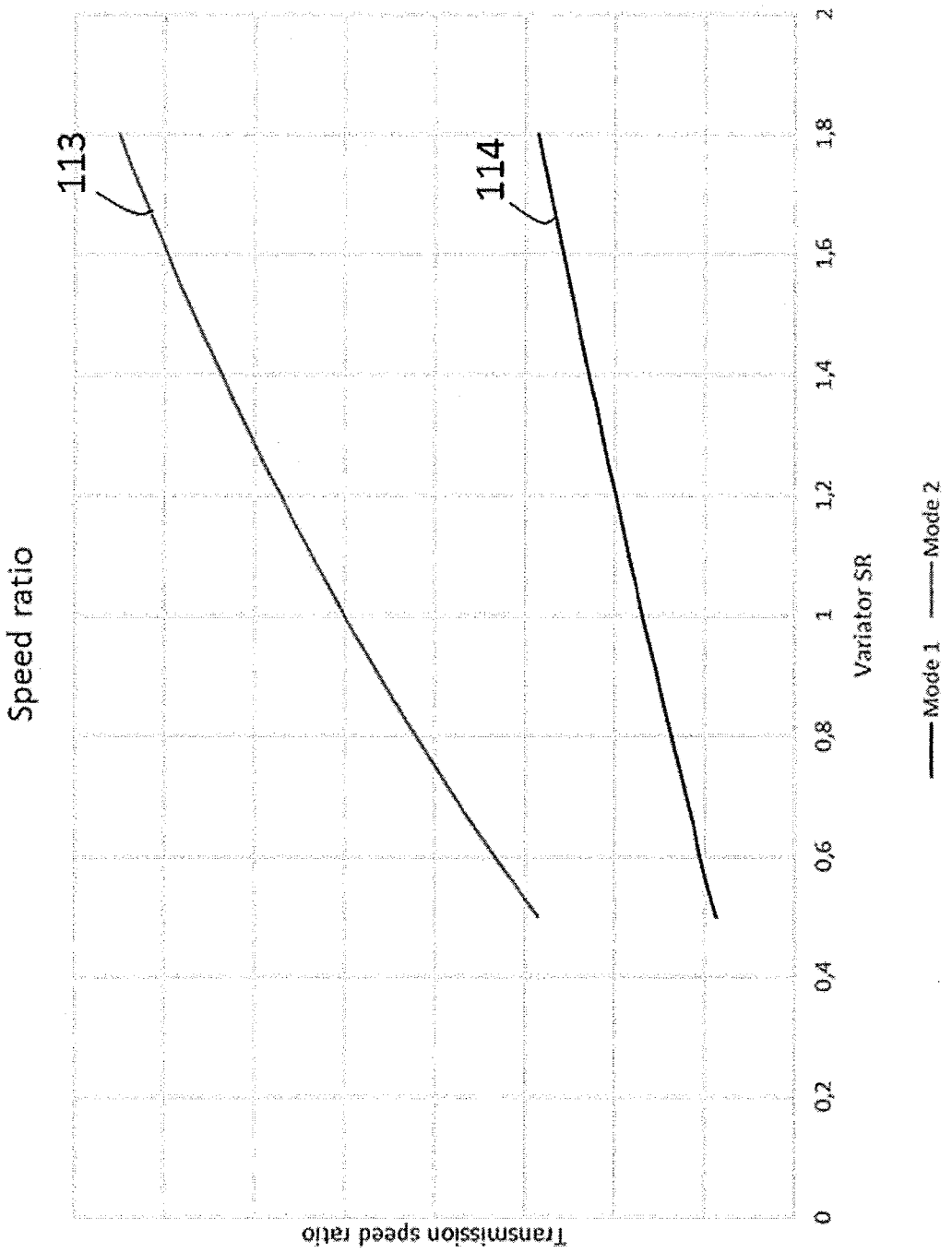

Speed ratio
Transmission speed ratio
113
114
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6
1,8
2
Variator SR
Mode 1
Mode 2

FIG. 7

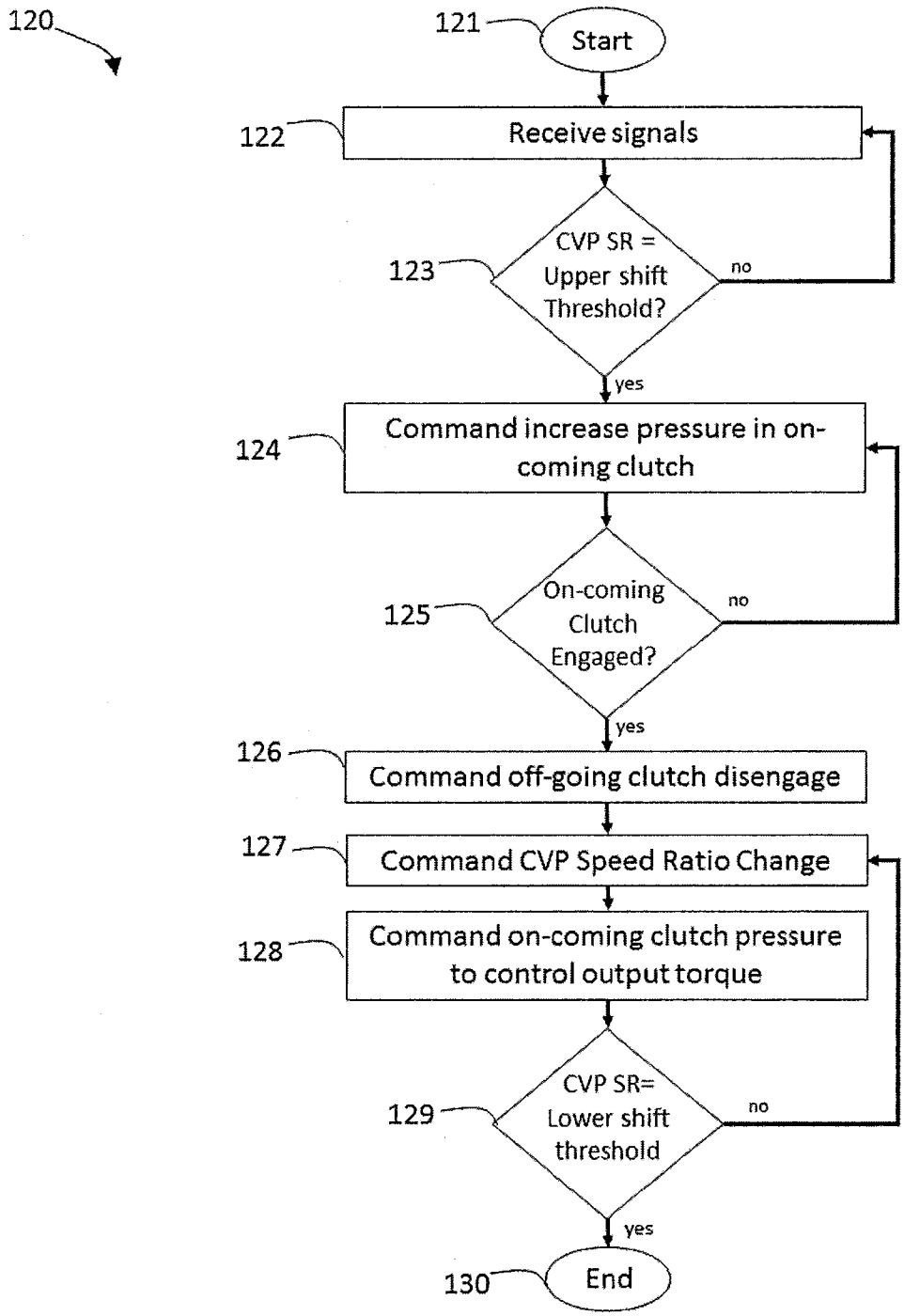

120
121
Start
122
Receive signals
123
CVP SR = Upper shift Threshold?
no
yes
124
Command increase pressure in on-coming clutch
125
On-coming Clutch Engaged?
no
yes
126
Command off-going clutch disengage
127
Command CVP Speed Ratio Change
128
Command on-coming clutch pressure to control output torque
129
CVP SR= Lower shift threshold
no
yes
130
End

Figure 8

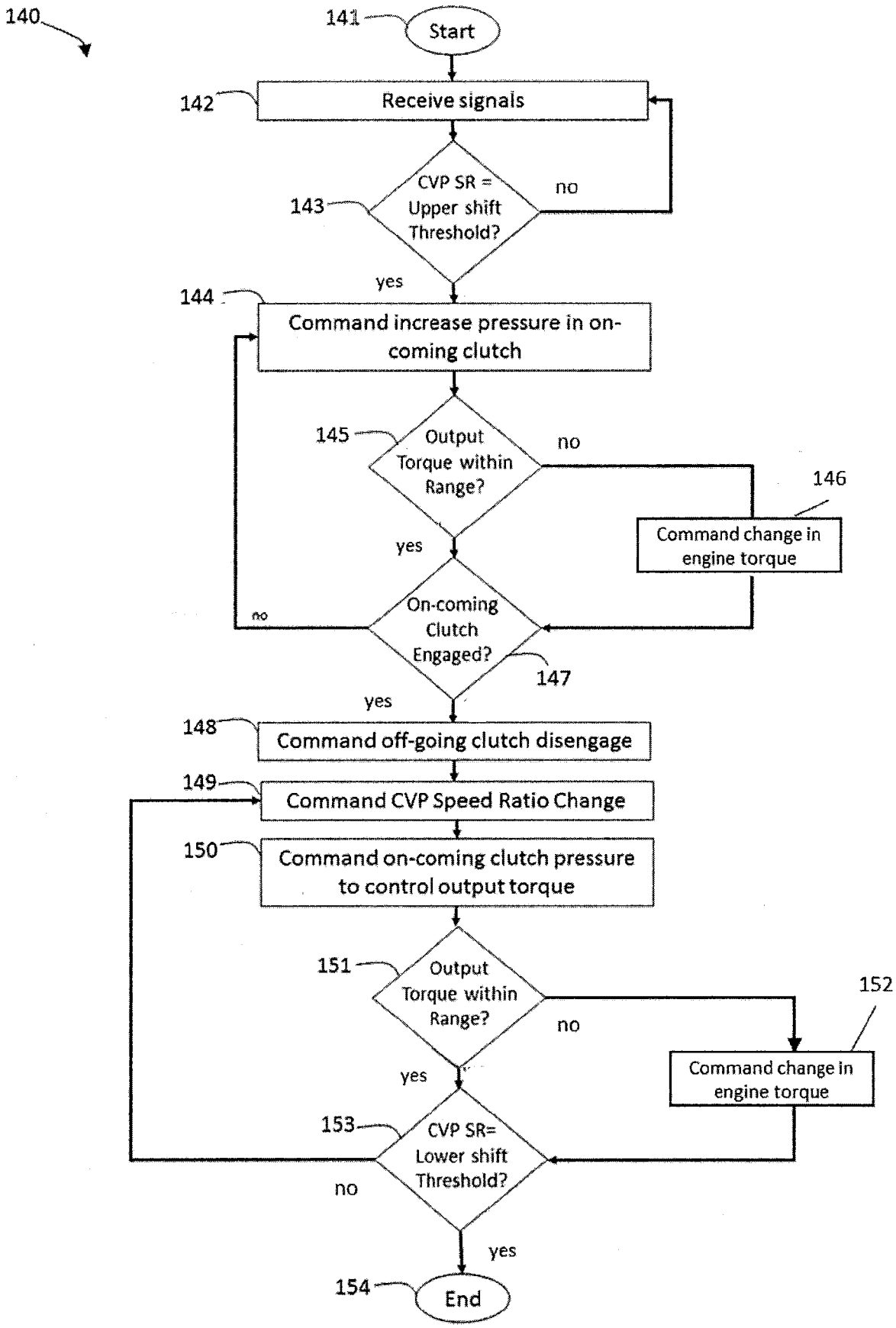

140
141
Start
142
Receive signals
143
CVP SR = Upper shift Threshold?
no
yes
144
Command increase pressure in on-coming clutch
145
Output Torque within Range?
no
146
Command change in engine torque
yes
On-coming Clutch Engaged?
no
147
yes
148
Command off-going clutch disengage
149
Command CVP Speed Ratio Change
150
Command on-coming clutch pressure to control output torque
151
Output Torque within Range?
152
no
Command change in engine torque
yes
153
CVP SR= Lower shift Threshold?
no
yes
154
End

Figure 9

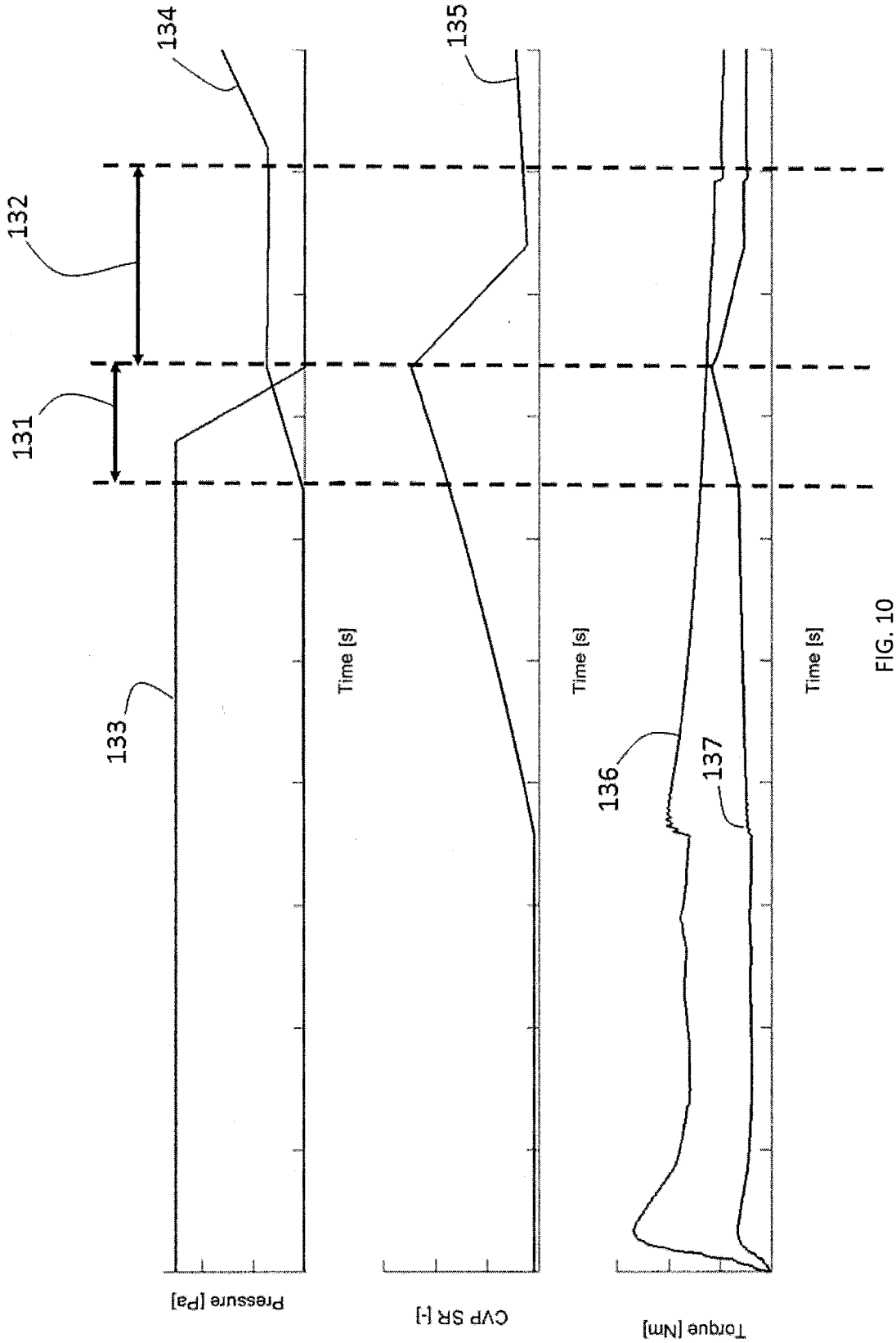

134
135
132
131
133
136
137
Time [s]
Time [s]
Time [s]
Pressure [Pa]
CVP SR [-]
Torque [Nm]

FIG. 10

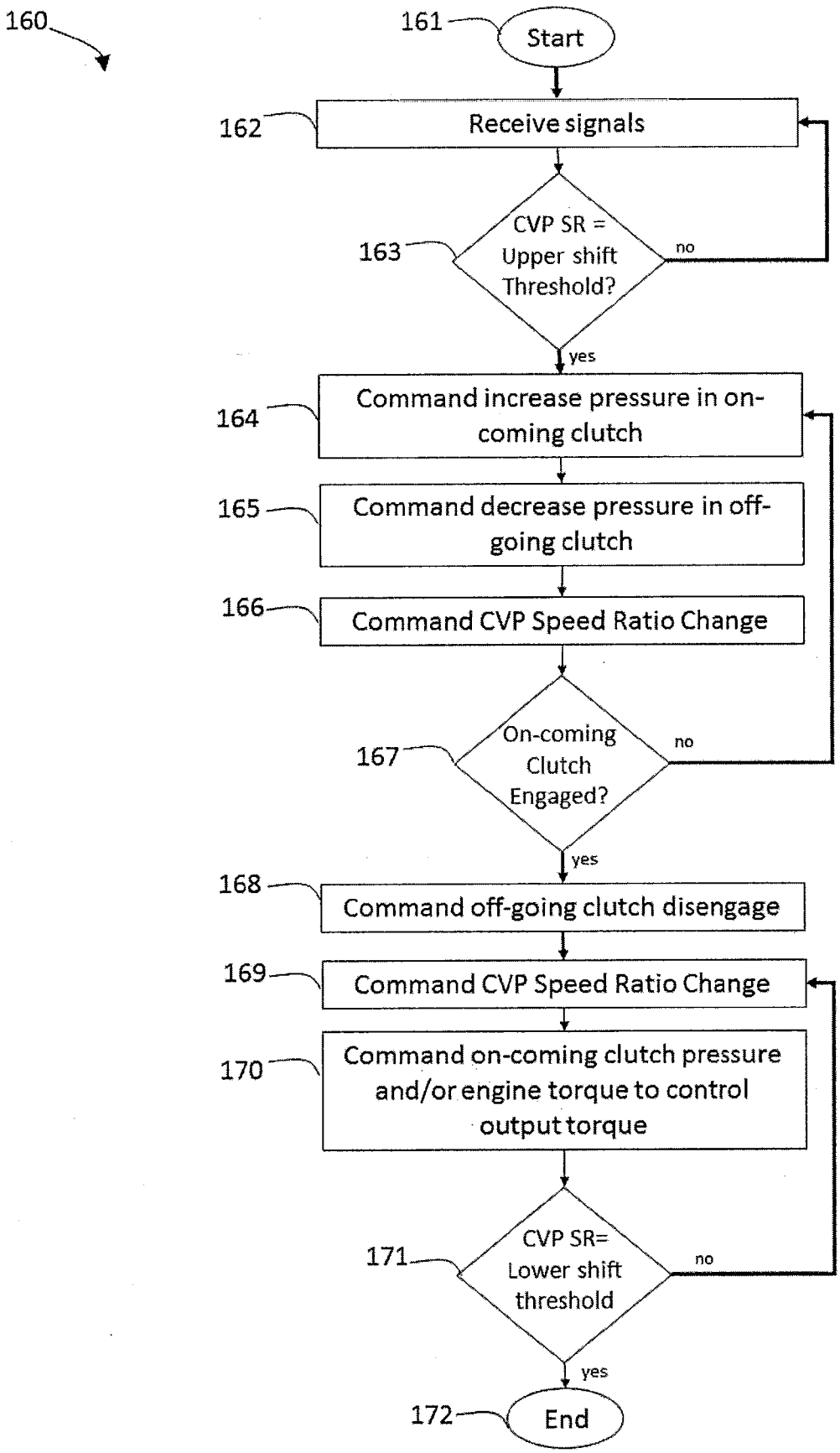

160
161
Start
162
Receive signals
163
CVP SR = Upper shift Threshold?
no
yes
164
Command increase pressure in on-coming clutch
165
Command decrease pressure in off-going clutch
166
Command CVP Speed Ratio Change
167
On-coming Clutch Engaged?
no
yes
168
Command off-going clutch disengage
169
Command CVP Speed Ratio Change
170
Command on-coming clutch pressure and/or engine torque to control output torque
171
CVP SR= Lower shift threshold
no
yes
172
End

Figure 11

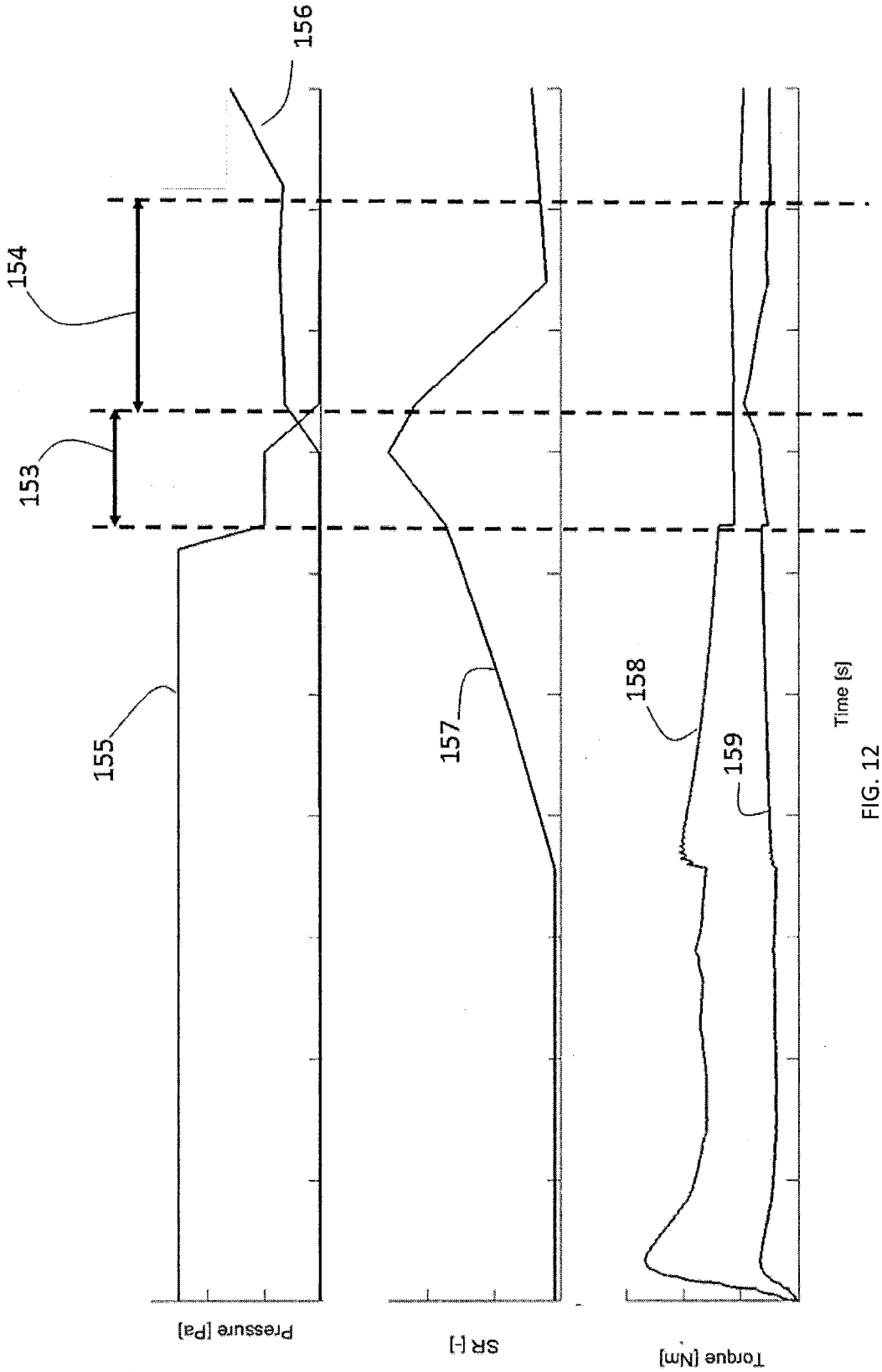


FIG. 12

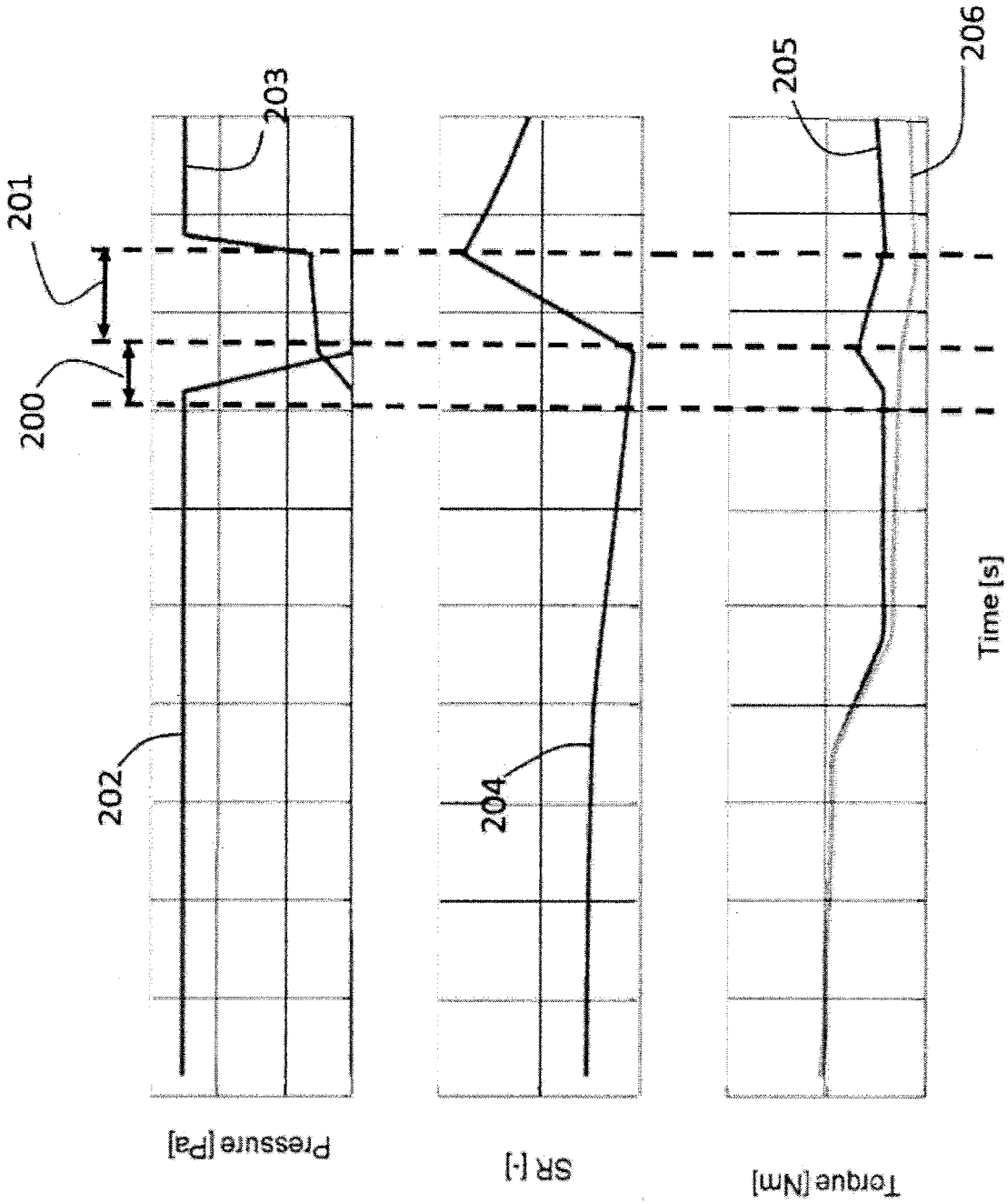


FIG. 13

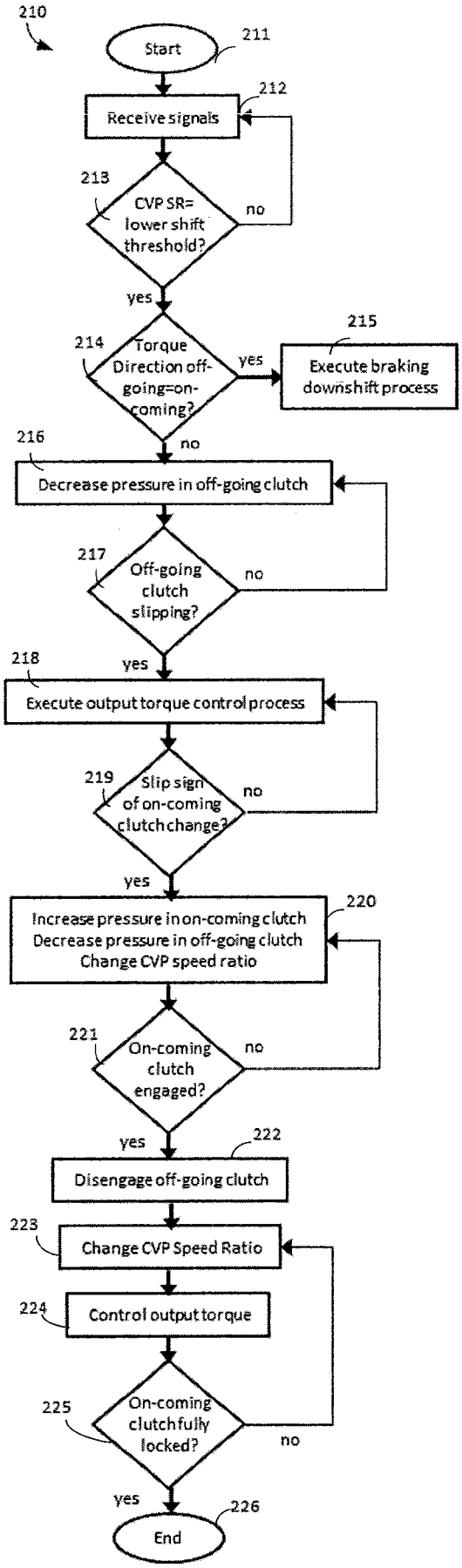

210
Start
211
Receive signals
212
CVP SR= lower shift threshold?
213
no
yes
Torque Direction off-going=on-coming?
214
yes
Execute braking downshift process
215
no
Decrease pressure in off-going clutch
216
Off-going clutch slipping?
217
no
yes
Execute output torque control process
218
Slip sign of on-coming clutch change?
219
no
yes
Increase pressure in on-coming clutch
Decrease pressure in off-going clutch
Change CVP speed ratio
220
On-coming clutch engaged?
221
no
yes
Disengage off-going clutch
222
Change CVP Speed Ratio
223
Control output torque
224
On-coming clutch fully locked?
225
no
yes
End
226

Figure 14

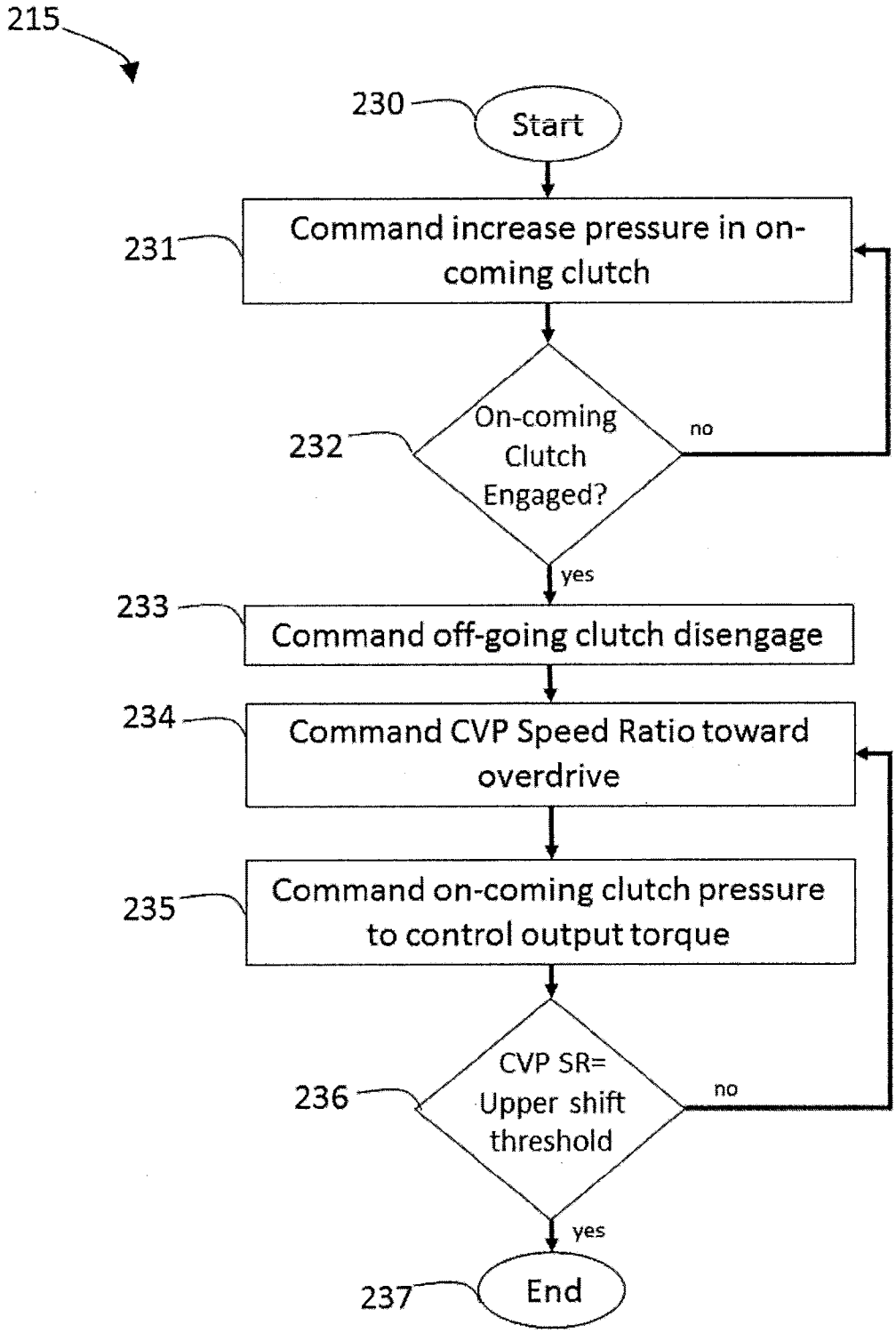

215
230
Start
231
Command increase pressure in on-coming clutch
232
On-coming Clutch Engaged?
no
yes
233
Command off-going clutch disengage
234
Command CVP Speed Ratio toward overdrive
235
Command on-coming clutch pressure to control output torque
236
CVP SR= Upper shift threshold
no
yes
237
End

Figure 15

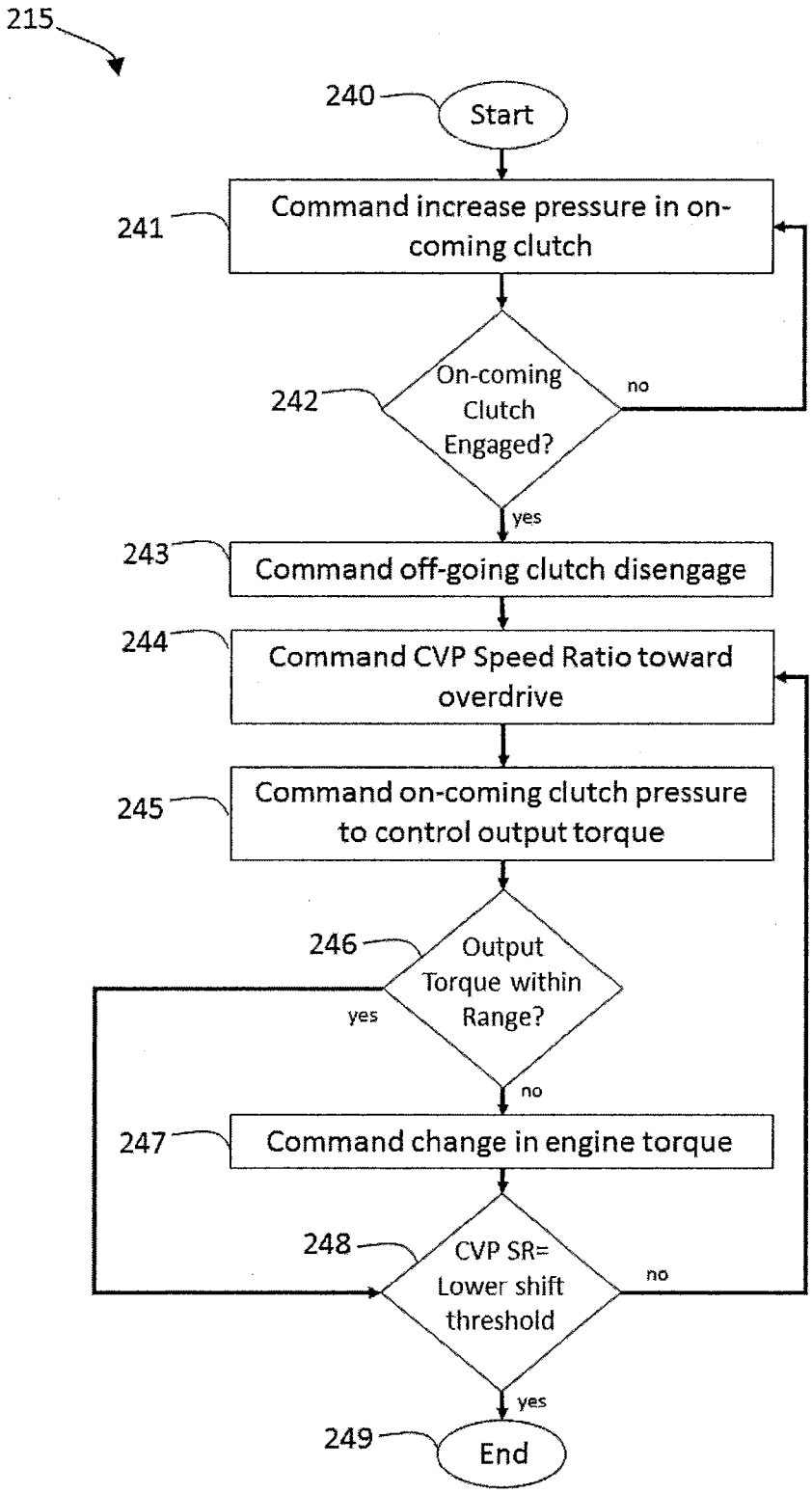

215
240
Start
241
Command increase pressure in on-coming clutch
242
On-coming Clutch Engaged?
no
yes
243
Command off-going clutch disengage
244
Command CVP Speed Ratio toward overdrive
245
Command on-coming clutch pressure to control output torque
246
Output Torque within Range?
yes
no
247
Command change in engine torque
248
CVP SR= Lower shift threshold
no
yes
249
End

Figure 16

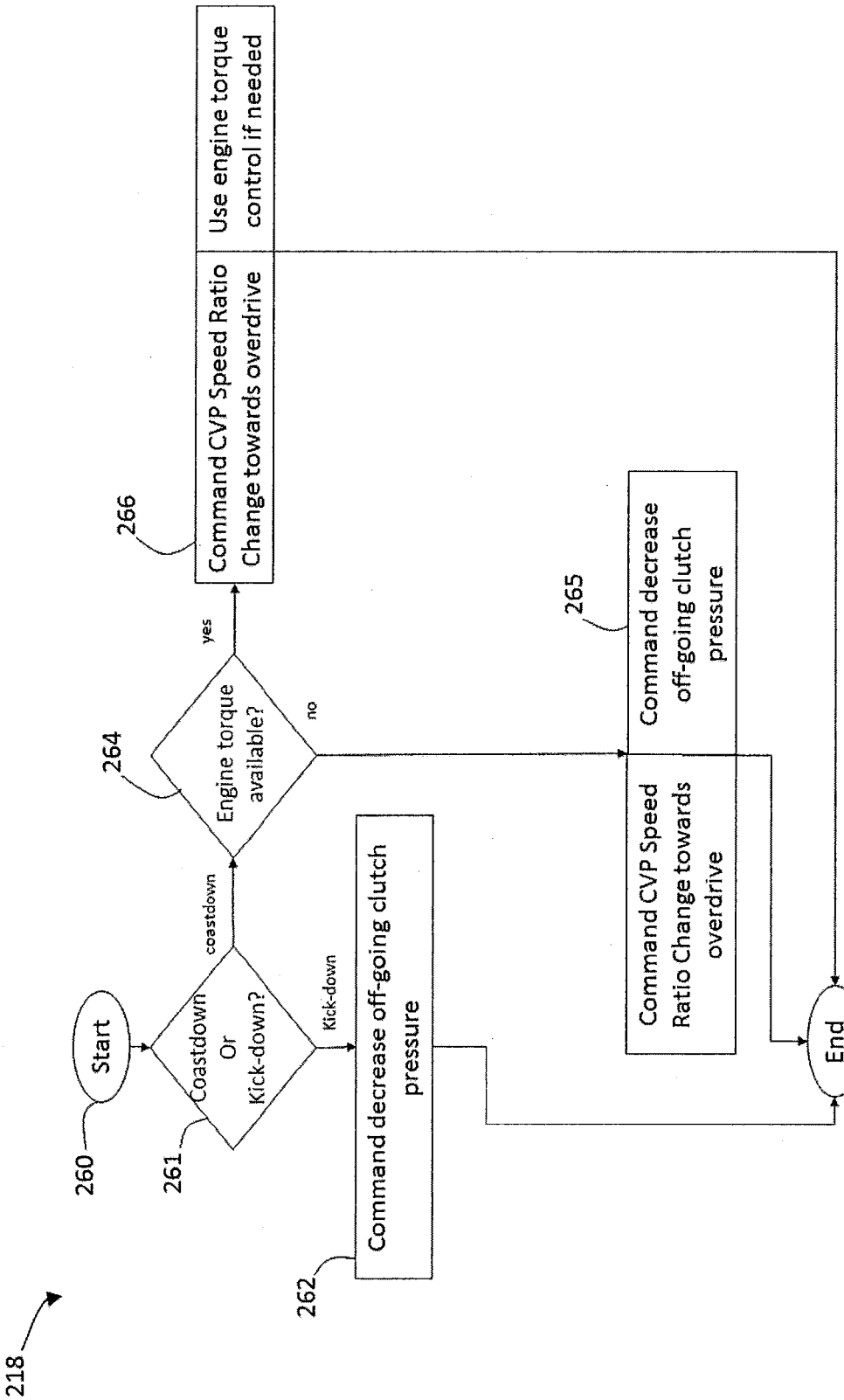

218
Start
260
Coastdown Or Kick-down?
261
coastdown
Kick-down
Engine torque available?
264
yes
no
Command CVP Speed Ratio Change towards overdrive
266
Use engine torque control if needed
Command decrease off-going clutch pressure
262
Command decrease off-going clutch pressure
265
Command CVP Speed Ratio Change towards overdrive
End
263

Figure 17

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/012768

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16H61/664
ADD. F16H61/66

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F16H

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2016/182838 A1 (DANA LTD [US]) 17 November 2016 (2016-11-17) figures 1,2,3,4,5,7, 9,10,13,16, paragraphs [0007], [0008], [0009], [0056], [0067], [0069] claims 1-46	1-18
A	US 3 406 597 A (BRIE PERRY FORBES GEORGE DE ET AL) 22 October 1968 (1968-10-22) the whole document	1-18

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

☒ See patent family annex.

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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

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 April 2018	11/04/2018

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	Ehrsam, Adrian

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2018/012768

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2016182838 A1	17-11-2016	CN 107532692 A	02-01-2018
		EP 3295057 A1	21-03-2018
		WO 2016182838 A1	17-11-2016
US 3406597 A	22-10-1968	DE 1500460 B1	05-08-1971
		DE 1775908 A1	13-01-1972
		FR 1464924 A	06-01-1967
		GB 1078791 A	09-08-1967
		NL 6515563 A	02-06-1966
		SE 324937 B	15-06-1970
		SE 356800 B	04-06-1973
		US 3406597 A	22-10-1968