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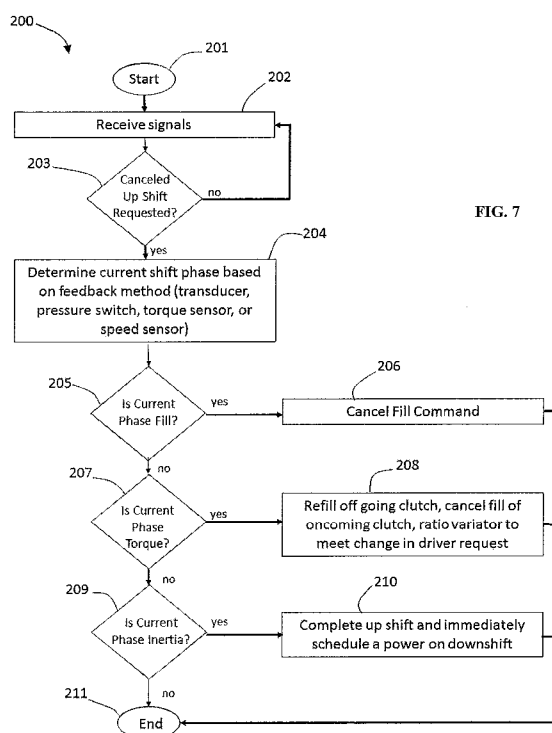


FIG. 7

(57) Abstract: Provided herein is a control system for a multiple-mode continuously variable transmission having a ball-type 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 transmission control module includes a CVP control module and a clutch control module. The transmission control module is configured to control the variator and the clutches during a canceled power on upshift, a canceled power on downshift, and a transition shift based on a driver's command.

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CANCELED SHIFT AND TRANSITIONAL SHIFT CONTROL METHODS
FOR A MULTI-MODE BALL-TYPE CONTINUOUSLY
VARIABLE TRANSMISSION

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RELATED APPLICATIONS

The present application claims the benefit of U.S. Provisional Application No. 62/465,387 filed on March 1, 2017 and U.S. Provisional Application No. 62/570,144 filed on October 10, 2017, which are incorporated herein by reference in their entirety.

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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.

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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.

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SUMMARY

Provided herein is 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, wherein the CVP

is operably coupled to a multiple speed gear box having a plurality clutches corresponding to selectable operating modes, the method including the steps of: receiving a plurality of data signals provided by sensors located on the transmission, the plurality of data signals including a CVP speed ratio, an accelerator pedal position, a first clutch pressure corresponding to a control pressure of a first clutch of the multiple speed gear box, a second clutch pressure corresponding to a control pressure of a second clutch of the multiple speed gear box, and a CVD output torque; detecting a canceled upshift based on the accelerator pedal position; evaluating a current shift phase for an on-coming clutch based on the first clutch pressure; evaluating a current shift phase for an off-going clutch based on the second clutch pressure; commanding a cancelation of a fill command of the on-coming clutch corresponding to the current shift phase being a fill phase of the on-coming clutch; commanding a refill of the off-going clutch, cancelation of a fill of the on-coming clutch, and a change in the CVP speed ratio corresponding to the current shift phase being a torque phase of the on-coming clutch; and commanding a downshift from the on-coming clutch to the off-going clutch corresponding to the current shift phase being an inertia phase of the on-coming clutch. In some embodiments, the method further includes commanding a reduction in capacity of the on-coming clutch prior to commanding the cancellation of fill of the on-coming clutch. In some embodiments, the method further includes commanding an adjustment to a target pressure of the on-coming clutch, wherein the target pressure is determined by a requested CVD output torque.

Provided herein is 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, wherein the CVP is operably coupled to a multiple speed gear box having a plurality clutches corresponding to selectable operating modes, the method including the steps of: receiving a plurality of data signals provided by sensors located on the transmission, the plurality of data signals including a CVP speed ratio, an accelerator pedal position, a first clutch pressure corresponding to a control pressure of a first clutch of the multiple speed gear box, a second clutch

pressure corresponding to a control pressure of a second clutch of the multiple speed gear box, and a CVD output torque; detecting a canceled downshift based on the accelerator pedal position; evaluating a current shift phase for an on-coming clutch based on the first clutch pressure; evaluating a current shift
5 phase for an off-going clutch based on the second clutch pressure; commanding a cancelation of a fill command of the on-coming clutch corresponding to the current shift phase being a fill state of the on-coming clutch; commanding a refill of the off-going clutch, cancelation of a fill of the on-coming clutch, and a change in the CVP speed ratio corresponding to the
10 current shift phase being an inertia phase of the on-coming clutch; and commanding an upshift from the on-coming clutch to the off-going clutch corresponding to the current shift phase being a torque phase of the on-coming clutch. In some embodiments, the method further includes wherein the change in CVP speed ratio is determined by the accelerator pedal position.

15 Provided herein is 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, wherein the CVP is operably coupled to a multiple speed gear box having a plurality of clutches corresponding to selectable operating modes, the method including the steps
20 of: receiving a plurality of data signals provided by sensors located on the transmission, the plurality of data signals including a CVP speed ratio, an accelerator pedal position, a first clutch pressure corresponding to a control pressure of a first clutch of the multiple speed gear box, a second clutch pressure corresponding to a control pressure of a second clutch of the multiple
25 speed gear box, and a CVD output torque; detecting a transition shift based on the accelerator pedal position; selecting a first target on-coming clutch; evaluating a current shift phase for the target on-coming clutch based on the first clutch pressure; evaluating a current shift phase for an off-going clutch based on the second clutch pressure; commanding a release of the off-going
30 clutch corresponding to the current shift phase being an inertia phase of the on-coming clutch; and commanding a downshift from the off-going clutch to the first target on-coming clutch corresponding to the current shift phase being an torque phase. In some embodiments, the method further includes commanding

a cancelation of a fill of the first target on-coming clutch corresponding to the current shift phase being a fill state of the on-coming clutch and filling a second target on-coming clutch.

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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.

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BRIEF DESCRIPTION OF THE DRAWINGS

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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.

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Figure 2 is a plan view of a carrier member that used in the ball-type 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 implementable by a vehicle.

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Figure 5 is a schematic diagram of an exemplary continuously variable drive configured to be controlled 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.

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Figure 7 is a flow chart depicting a power on upshift control process implementable in the vehicle control system of Figure 4.

Figure 8 is a flow chart depicting a power on downshift control process implementable in the vehicle control system of Figure 4.

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

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

5 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.

10 The electronic controller can be configured to receive input signals indicative of parameters associated with an engine coupled to the transmission.

The parameters can 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.

15 The electronic controller can determine an active range and an active variator mode based on the input signals and control inputs.

20 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.

25 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 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
30 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 6, 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 6, 7 to impart a tilting of the axles 5 and thereby adjusts the speed ratio of the variator 1. 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 can 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 be implemented as
5 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
10 hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans can 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.

15 For example, various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein can be 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
20 gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein.

A general-purpose processor can be a microprocessor, but in the alternative, the processor can be any conventional processor, controller, microcontroller, or state machine. A processor can also be implemented as a
25 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 can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a
30 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 could be 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).

5 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
10 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.

15 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.

20 The transmission control module 104 optionally 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
25 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
30 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 here.

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 Application No. PCT/US2017/026,041, 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 second-and-fourth mode clutch 184 is configured to selectively couple the third sun gear 192 to a grounded member. The third planet carrier 191 is coupled to the second ring gear 186. The first-and-reverse mode clutch 182 is configured to selectively couple the third planet carrier 191 to a grounded member. 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, a 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, a 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 a first mode of operation (mode 1), the forward mode clutch 180 and the first-and-reverse mode clutch 182 are engaged. For a second mode of operation (mode 2), the forward mode clutch 180 and the second-and-fourth mode clutch 183 are engaged. For a third mode of operation (mode 3) operation, the forward mode clutch 180 and the third-and-fourth mode clutch 184 are engaged. For a fourth mode of operation (mode 4), the forward mode clutch 180, the second-and-fourth mode clutch 183, and the third-and-fourth mode clutch 184 are engaged. For a reverse mode operation, the first-and-reverse mode clutch 182 and the reverse mode clutch 181 are engaged.

Shifting of gears is accomplished by selectively engaging and disengaging clutching devices. A shift or a power shift may usually be decomposed into at least two phases: a torque phase where torque is transferred from one clutch to the other, and an inertia phase. Corresponding changes in inertia of rotating components, such as the clutching devices, occur.

In some embodiments, the clutching devices are hydraulically actuated, receiving pressurized hydraulic fluid from a pump (not shown).

In some embodiments, a hydraulic clutch shift also includes a fill phase where hydraulic fluid is provided to fill or pressurize the clutch to be engaged (also denoted on-coming clutch).

In the described variator equipped transmission, 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 during the shift, thus eliminating the stepped change in ratio and associated shift feel of typical automatic transmissions. CVP ratio control during the shift is used to continuously and actively adjust the output torque based on accelerator pedal position and vehicle speed to minimize driver disturbance.

In some embodiments, an engine throttle position, an engine manifold air pressure, or other load sensing parameter is optionally used in the CVP ratio control.

An illustrative example of CVP ratio control methods during shifts in mode of operation are described in Patent Cooperation Treaty Patent Application No. PCT/US2018/012768, which is hereby incorporated by reference.

During operation of multi-mode continuously variable transmissions, a variety of shift conditions may occur that require control methods to be implemented in the transmission control module 104. Control methods are described below in reference to the CVD depicted 175; however, the control method can be implement on various multi-mode continuously variable transmissions includes those are depicted in United States Patent Application No. 62/465,387, which is hereby incorporated by reference.

For description purposes, examples of shift conditions encountered during operation of the CVD 175 will be described including canceled power on upshift, canceled power on downshift, double transition shifts; however, other shift conditions can be encountered.

Canceled Power On Upshift

A canceled power on upshift occurs when the driver or operator, adjusts the accelerator pedal position to indicate a request for more torque output of the vehicle during a commanded upshift. The adjustment in the accelerator pedal position is sometimes referred to as a "tip" or "tip-in" event. Corresponding control processes implemented by the transmission control module 104 are dependent on the current phase of the commanded upshift.

Described herein is a canceled power upshift from mode 1 to mode 2; however, it should be appreciated that other canceled power upshift between modes can be accomplished.

In some embodiments, when an upshift from a first mode (mode 1) to a second mode (mode 2) for the CVD 175 is commanded by the transmission control module 104, or optionally the clutch control module 108, and the transmission control module 104 detects a canceled shift based on the driver's command from a sensor signal indicating the accelerator pedal position, or other known sensor. The transmission control module 104 evaluates the current shift phase of the on-coming clutch 183 of the CVD 175 and the transmission control module 104 is adapted to provide corresponding control commands depending on the shift phase of the on-coming clutch 183.

If the on-coming clutch 183 is in a fill phase, the transmission control module 104, or optionally the clutch control module 108, commands stoppage or cancellation of filling of the on-coming clutch 183 and commands the off-going clutch 182 remains engaged. The CVP control module 110 does not execute additional steps and continues to operate in a state of normal operation.

If the on-coming clutch 183 is in a torque phase, the transmission control module 104, or optionally the clutch module 108, commands the release/cancellation of filling of the on-coming clutch 183, and commands engagement/refilling of the off-going clutch 182.

In some embodiments, a command to reduce the capacity of the on-coming clutch 183 is executed prior to the release of the on-coming clutch 183.

In some embodiments, capacity of the on-coming clutch 183 is controlled through hydraulic pressure. The CVP control module 110 commands adjustment of the CVP ratio corresponding to the driver request. In some embodiments, the driver request is received through the accelerator pedal position.

If the on-coming clutch 183 is in an inertia phase, the transmission control module 104, or optionally the clutch control module 108, proceeds with the commanded upshift from mode 1 to mode 2, and upon completion of the shift, commands a downshift from mode 2 to mode 1. In some embodiments,

the downshift from mode 2 to mode 1 is referred to as a “power on downshift” or a “powered downshift”. The CVP control module 110 commands the variator to operate in a normal operating mode during a powered downshift.

During the inertia phase of the power on upshifts, the pressure of the on-coming clutch determines the output torque. If the acceleration pedal position sets a desired output torque, variations of the accelerator pedal position corresponds directly to the pressure setpoint of the on-coming clutch.

In some embodiments, the clutch control module 108 includes one or more calibration tables or calibration maps, and associated control processes, to determine the pressure setpoint of the on-coming clutch based at least in part on the desired output torque. In some embodiments, the desired output torque is indicated by the accelerator pedal position.

Tip-out Upshift

In some embodiments, during operation, when the transmission control module 104 determines that a power on upshift is appropriate, based on the signal received from sensors indicating various parameters including, but not limited to, vehicle speed and the accelerator pedal position, and then the driver adjusts the accelerator pedal position indicating a reduction in the requested output torque, sometimes referred to herein as “tip out” of the accelerator pedal during the shift, a completion of the upshift is commanded.

In some embodiments, the transmission control module 104, or optionally the clutch control module 108, commands an adjustment to a target pressure of on-coming clutch during the upshift corresponding to the requested output torque, which may provide a smoother shift.

Canceled Power On Downshift

A canceled power on downshift occurs when the driver releases the accelerator pedal during the shift. The commands provided by the transmission control module 104 depend on the current shift phase of the on-coming clutch 183 in a downshift from a first mode (mode 3) to a second mode (mode 2). Described herein is a canceled power downshift from mode 3 to

mode 2; however, it should be appreciated that other canceled power upshift between modes can be accomplished.

If the oncoming-clutch 182 is in a fill phase, the transmission control module 104, or optionally the clutch control module 108, commands stoppage or cancellation of filling of the on-coming clutch 183.

If the on-coming clutch 183 is in an inertia phase, the transmission control module 104, or optionally the clutch control module 108, commands the stoppage or cancellation of filling of the on-coming clutch 183, holding the on-coming clutch 183 in the current shift phase, and re-engaging or refilling the off-going clutch 184. The CVP control module 110 commands adjustment of the CVP ratio corresponding to the driver request. In some embodiments, the driver request is received through the accelerator pedal position.

If the current shift phase of the clutch 183 is in the torque phase, the transmission control module 104, or optionally the clutch control module 108, completes the downshift from mode 3 to mode 2, and then commands an upshift from mode 2 to mode 3.

Transitional Shifts

A transition shift occurs when the target gear changes during a shift event. The commands given by the transmission control module 104 depends on which clutching devices are to be engaged or released to achieve the shift.

Described herein is an illustrative transition shift including a downshift from mode 3 to mode 2 that changes to a mode 3 to mode 1 downshift; however, it should be appreciated that other transition shifts between modes can be accomplished. In this illustrative example, the off-going clutch 184 is the same for both downshifts, therefore, if the transition occurs during the inertia phase or at the beginning of the torque phase, the transmission control module 104 commands a switch to the on-coming clutch from the second-and-fourth mode clutch 183 to the first-and-reverse mode clutch 182. The CVP control module 110 targets an output torque appropriate for the new target gear.

In some embodiments, a large step change in CVP ratio is desirable, for example a change in CVP ratio from underdrive to 1:1, from overdrive to 1:1, or from underdrive to overdrive. If the change in target gear occurs toward the end of the torque phase of the shift, the transmission control module 104 will complete the mode 3 to mode 2 downshift and then immediately command the mode 2 to mode 1 downshift.

It should be appreciated that the control methods described herein are applicable to a variety of continuously variable devices. In alternative embodiments, a continuously variable device may be configured to have a common on-coming clutch for multiple modes of operation. For example, a first mode clutch may be engaged for operating a first mode (mode 1) and a second mode (mode 2), while separate clutches are engaged to correspond to the second mode (mode 2) and a third mode (mode 3) operation, a second mode clutch and a third mode clutch, respectively.

In some embodiments, the transition shift for a continuously variable device having multiple modes includes a common on-coming clutch for a shift from a third mode (mode 3) to a second mode (mode 2) downshift to a third mode (mode 3) to a first mode (mode 1) downshift, but different off-going clutches. If the on-coming clutch, for example the second mode clutch, is in the beginning of the inertia phase, the transmission control module 104 commands the re-engagement of the third mode clutch and disengagement of the second mode clutch, and engagement of the first mode clutch followed by release of the third mode clutch. If second mode clutch is at the end of the inertia phase or in the torque phase, the transmission control module 104 commands the completion of the mode 3 to mode 2 downshift and immediately commands a mode 2 to mode 1 downshift.

Double Transition Shifts

A double transition shift occurs when, due to a large step change in throttle or accelerator pedal, for example a change from 5% accelerator pedal position to 100% accelerator pedal position, a multi-step skip shift is requested. It should be appreciated that it is within a designer's or calibrator's means to determine the quantity of the step change corresponding to a double transition

shift. A double transition shift requires two off-going clutches and two on-coming clutches and can be handled as two separate downshift events. A mode 4 to mode 1 downshift of the CVD 175 depicted in FIG. 5 is provided as an example below; however, various double transition operational modes shifts of alternative CVD's can be used.

A mode 4 to mode 1 downshift requires the release of the third-and-fourth mode clutch 184 and the second-and-fourth mode clutch 183, and a fill of forward mode clutch 180 and the first-and-reverse mode clutch 182. Instead of simultaneously trying to control multiple on-coming and off-going clutches, the transmission control module 104 commands a first downshift (mode 4 to mode 2 downshift), releasing the third-and-fourth mode clutch 184 and filling the forward mode clutch 180, followed by a second downshift (a mode 2 to mode 1 downshift) releasing the second-and-fourth mode clutch 183 and filling the first-and-reverse mode clutch 182.

Turning now to FIG. 7, in some embodiments, the clutch control module 108 initiates a canceled power on upshift control process 200 that begins at a start state 201 and proceeds to a block 202 where a number of signals are received. For example, the block 202 receives a CVP speed ratio, a first clutch pressure, a second clutch pressure, an accelerator pedal position, a CVP output torque, among others.

The canceled power on upshift control process 200 proceeds to a first evaluation block 203 where a request for a canceled upshift is evaluated. In some embodiments, a canceled power on upshift is detected based on the accelerator pedal position. If the first evaluation block 203 returns a false result, indicating that there is no request for a canceled upshift, the control process 200 returns to the block 202. If the first evaluation block 203 returns a true result, indicating that there is a request for a canceled upshift, the control process 200 proceeds to a block 204. The block 204 is configured to determine the current shift phase of a CVD 175. In some embodiments, a pressure transducer, a pressure switch, a torque sensor, and/or a speed sensor are used to determine the current shift phase.

The control process 200 proceeds to a second evaluation block 205 where the current shift phase of the on-coming clutch is evaluated for a fill

phase. If the second evaluation block 205 returns a true result, corresponding to the clutch shift phase being in a fill state, for example, based on the pressure of the on-coming clutch, then the control process 200 proceeds to a block 206 where a command is sent to cancel the filling of the on-coming clutch.

5 In some embodiments, the fill state is detected through a pressure sensor in fluid communication with the clutch, a transducer in communication with the clutch, a torque sensor equipped on the CVD 175, or speed sensor, among other feedback techniques.

If the second evaluation block 205 returns a false result, the control
10 process 200 proceeds to a third evaluation block 207 where the current shift phase for the on-coming clutch is evaluated for a torque phase through aforementioned feedback techniques. If the third evaluation block 207 returns a true result, corresponding to the on-coming clutch shift phase being in a torque phase, then the control process 200 proceeds to a block 208 where
15 commands are sent to refill the off-going clutch, cancel the filling of the on-coming clutch, and changing the ratio of the variator to meet the change in driver request.

In some embodiments, the change in the ratio of the variator is implemented in the CVP control module 110.

20 If the third evaluation block 207 returns a false result, the control process 200 proceeds to a fourth evaluation block 209 where the current shift phase of the on-coming clutch is evaluated for an inertia phase. If the fourth evaluation block 209 returns a true result, corresponding to the clutch shift phase being in an inertia phase, then the control process 200 proceeds to a block 210 where a
25 command is sent to complete the upshift and immediately command a power on downshift. If the fourth evaluation block 209 returns a false result, the control process 200 proceeds to an end state 211.

Referring now to FIG. 8, in some embodiments, a canceled power on downshift control process 215 begins at a start state 216 and proceeds to a
30 block 217 where a number of signals are received. For example, the block 217 receives a CVP speed ratio, a first clutch pressure, a second clutch pressure, an accelerator pedal position, a CVP output torque, among others.

The canceled power on downshift control process 215 proceeds to a first evaluation block 218 where a request for a canceled downshift is evaluated. In some embodiments, a canceled power on downshift is detected based on the accelerator pedal position. If the first evaluation block 218 returns a false
5 result, the control process 215 returns to the block 217. If the first evaluation block 218 returns a true result, the control process 215 proceeds to a block 219. The block 219 is configured to determine the current shift phase of the CVD 175, for example. In some embodiments, a transducer, a pressure switch, a torque sensor, and/or a speed sensor are used to determine the
10 current shift phase.

The control process 215 proceeds to a second evaluation block 220 where the current shift phase is evaluated for a fill phase. If the second evaluation block 220 returns a true result, corresponding to the on-coming clutch shift phase being in a fill state, then the control process 215 proceeds to
15 a block 221 where a command is sent to cancel the filling of the on-coming clutch. If the second evaluation block 220 returns a false result, the control process 215 proceeds to a third evaluation block 222 where the current shift phase for the on-coming clutch is evaluated for an inertia phase. If the third evaluation block 222 return a true result, corresponding to the clutch shift
20 phase being in an inertia phase, then the control process 215 proceeds to a block 223 where commands are sent to refill the off-going clutch, cancel the filling of the on-coming clutch, and changing the ratio of the variator to meet the change in driver request.

The CVP control module 110 commands adjustment of the CVP ratio
25 corresponding to the driver request. In some embodiments, the driver request is received through the accelerator pedal position.

If the third evaluation block 222 returns a false result, the control process 215 proceeds to a fourth evaluation block 224 where the current shift phase is evaluated for a torque phase. If the fourth evaluation block 224 returns a true
30 result, corresponding to the on-coming clutch shift phase being in a torque phase, then the control process 215 proceeds to a block 225 where a command is sent to complete the downshift and immediately schedule a power

on upshift. If the fourth evaluation block 224 returns a false result, the control process 215 proceeds to an end state 211.

Referring now to FIG. 9, in some embodiments, a transition downshift shift control process 230 begins at a start state 231 and proceeds to a block 232 where a number of signals are received. For example, the block 230 receives a CVP speed ratio, a first clutch pressure, a second clutch pressure, an accelerator pedal position, a CVP output torque, among others.

The transition downshift control process 230 proceeds to a first evaluation block 233 where a request for a change in target gear or mode is evaluated, based on accelerator pedal position, vehicle speed, or variator ratio, among others. If the first evaluation block 233 returns a false result, the control process 230 returns to the block 232. If the first evaluation block 233 returns a true result, the control process 230 proceeds to a block 234. The block 234 is configured to determine the current shift phase of a CVD. In some embodiments, a transducer, a pressure switch, a torque sensor, and/or a speed sensor are optionally used to determine the current shift phase.

The control process 230 proceeds to a second evaluation block 235 where the current shift phase is evaluated for an inertia phase. If the second evaluation block 235 returns a true result, corresponding to the on-coming clutch shift phase being in an inertia phase, then the control process 230 proceeds to a block 236 where a command is sent to continue with the release of the off-going clutch, if the transition shift shares a common off-going clutch as described previously. If the second evaluation block 235 returns a false result, the control process 230 proceeds to a third evaluation block 237 where the current shift phase for the on-coming clutch is evaluated for a fill state. If the third evaluation block 237 return a true result, corresponding to the clutch shift phase being in a fill phase, then the control process 230 proceeds to a block 238 where a command is sent to cancel the filling of the previous on-coming clutch and to begin filling phase of a new on-coming clutch. If the third evaluation block 237 returns a false result, the control process 230 proceeds to a fourth evaluation block 239 where the current shift phase is evaluated for a torque phase. If the fourth evaluation block 239 returns a true result, corresponding to the on-coming clutch shift phase being in a torque phase,

then the control process 230 proceeds to a block 240 where a command is sent to complete the downshift and immediately schedule a power on downshift. If the fourth evaluation block 239 returns a false result, the control process 230 proceeds to an end state 241.

5 It should be noted that the transitional downshift control process 230 described above is adaptable to a transitional upshift control process.

 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,
10 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.

15 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
20 embodiments described herein could be 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.

 Provided herein is a vehicle having the aspects including a continuously
25 variable drive (CVD) including: a first rotatable shaft operably coupleable to a source of rotational power, the first rotatable shaft forming a main axis; a continuously variable planetary (CVP), wherein 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
30 balls has a tiltable axis of rotation and wherein the ball variator assembly is coaxial with the main axis; 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;
and 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; and a controller configured to control a CVP
5 speed ratio, control the plurality of selectable operating modes, and detect a
canceled shift, wherein the controller commands a change in the CVP speed
ratio in coordination based on the detection of the canceled shift.

The vehicle described above including the aspect wherein the plurality of
selectable operating modes of the multiple speed gearbox further includes a
10 forward mode clutch, a first-and-reverse mode clutch, a second-and-fourth
mode clutch, a third-and-fourth mode clutch, and a reverse clutch.

The vehicle described above including the aspect wherein the controller
is configured to control a hydraulic control pressure to the forward mode clutch,
the first-and-reverse mode clutch, the second-and-fourth mode clutch, the third-
15 and-fourth mode clutch, and the reverse clutch.

The vehicle described above including the aspect wherein the controller
evaluates a current shift phase of the forward mode clutch, the first-and-reverse
mode clutch, the second-and-fourth mode clutch, the third-and-fourth mode
clutch, and the reverse clutch to determine a fill state, a torque phase, and an
20 inertia phase.

The vehicle described above including the aspect wherein the controller
is further configured to command a change in the command of the hydraulic
control pressure to the forward mode clutch, the first-and-reverse mode clutch,
the second-and-fourth mode clutch, the third-and-fourth mode clutch, and the
25 reverse clutch based on the detection of the canceled shift and the current shift
phase.

WHAT IS CLAIMED IS:

1. 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, wherein the CVP is operably coupled to a multiple speed gear box having a plurality of clutches corresponding to selectable operating modes, the method comprising the steps of:

receiving a plurality of data signals provided by sensors located on the transmission, the plurality of data signals comprising:

a CVP speed ratio,

an accelerator pedal position,

a first clutch pressure corresponding to a control pressure of a first clutch of the multiple speed gear box,

a second clutch pressure corresponding to a control pressure of a second clutch of the multiple speed gear box, and

a CVD output torque;

detecting a canceled upshift based on the accelerator pedal position;

evaluating a current shift phase for an on-coming clutch based on the first clutch pressure;

evaluating a current shift phase for an off-going clutch based on the second clutch pressure;

commanding a cancelation of a fill command of the on-coming clutch corresponding to the current shift phase being a fill phase of the on-coming clutch;

commanding a refill of the off-going clutch, cancelation of a fill of the on-coming clutch, and a change in the CVP speed ratio corresponding to the current shift phase being a torque phase of the on-coming clutch; and

commanding a downshift from the on-coming clutch to the off-going clutch corresponding to the current shift phase being an inertia phase of the on-coming clutch.

2. The method for controlling a CVD according to claim 1, further comprising commanding a reduction in capacity of the on-coming clutch prior to commanding the cancellation of fill of the on-coming clutch.

5 3. The method for controlling a CVD according to claim 1, further comprising the step of commanding an adjustment to a target pressure of the on-coming clutch, wherein the target pressure is determined by a requested CVD output torque.

10 4. 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, wherein the CVP is operably coupled to a multiple speed gear box having a plurality of clutches corresponding to selectable operating modes, the method comprising the steps of:

15 receiving a plurality of data signals provided by sensors located on the transmission, the plurality of data signals comprising:

a CVP speed ratio,

an accelerator pedal position,

20 a first clutch pressure corresponding to a control pressure of a first clutch of the multiple speed gear box,

a second clutch pressure corresponding to a control pressure of a second clutch of the multiple speed gear box, and

a CVD output torque;

25 detecting a canceled downshift based on the accelerator pedal position;
evaluating a current shift phase for an on-coming clutch based on the first clutch pressure;

evaluating a current shift phase for an off-going clutch based on the second clutch pressure;

30 commanding a cancellation of a fill command of the on-coming clutch corresponding to the current shift phase being a fill state of the on-coming clutch;

commanding a refill of the off-going clutch, cancelation of a fill of the on-coming clutch, and a change in the CVP speed ratio corresponding to the current shift phase being an inertia phase of the on-coming clutch; and

commanding an upshift from the on-coming clutch to the off-going clutch corresponding to the current shift phase being a torque phase of the on-coming clutch.

5 5. The method for controlling a CVD according to claim 4, wherein the change in CVP speed ratio is determined by the accelerator pedal position.

10 6. 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, wherein the CVP is operably coupled to a multiple speed gear box having a plurality clutches
15 corresponding to selectable operating modes, the method comprising the steps of:

 receiving a plurality of data signals provided by sensors located on the transmission, the plurality of data signals comprising:

 a CVP speed ratio,

20 an accelerator pedal position,

 a first clutch pressure corresponding to a control pressure of a first clutch of the multiple speed gear box,

 a second clutch pressure corresponding to a control pressure of a second clutch of the multiple speed gear box, and

25 a CVD output torque;

 detecting a transition shift based on the accelerator pedal position;

 selecting a first target on-coming clutch;

 evaluating a current shift phase for the target on-coming clutch based on the first clutch pressure;

30 evaluating a current shift phase for an off-going clutch based on the second clutch pressure;

commanding a release of the off-going clutch corresponding to the current shift phase being an inertia phase of the on-coming clutch; and

commanding a downshift from the off-going clutch to the first target on-coming clutch corresponding to the current shift phase being an torque phase.

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7. The method for controlling a CVD according to claim 6, further comprising commanding a cancelation of a fill of the first target on-coming clutch corresponding to the current shift phase being a fill state of the on-coming clutch and filling a second target on-coming clutch.

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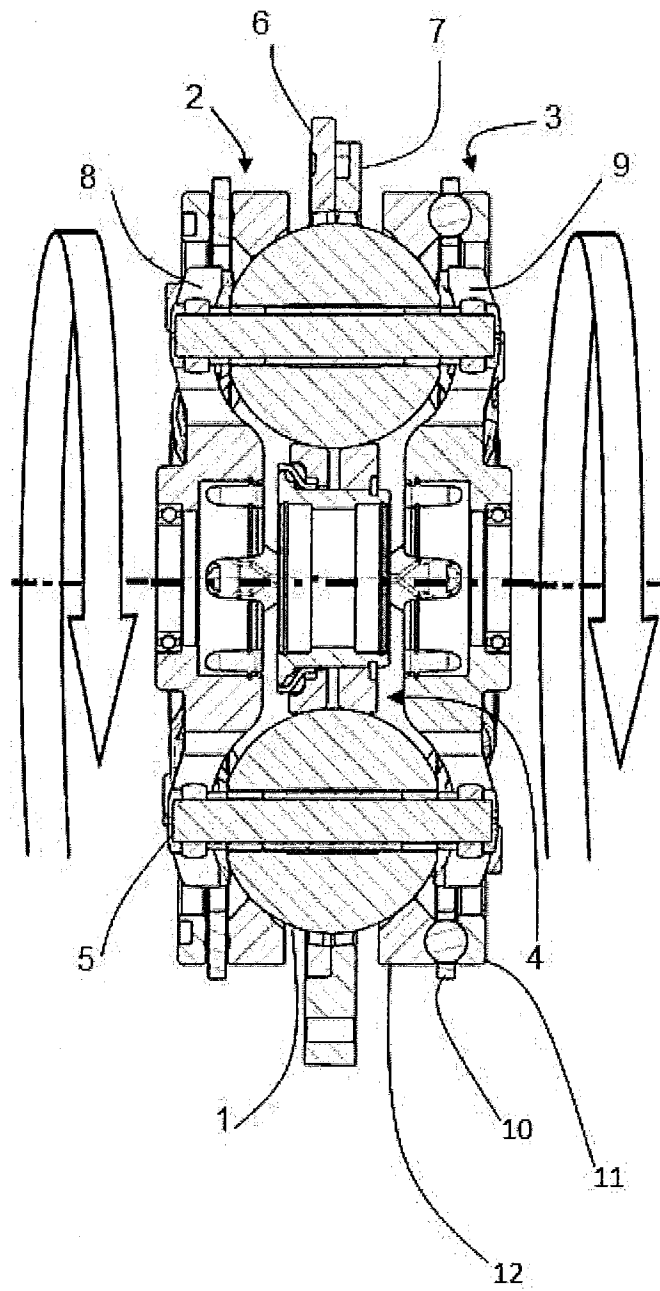


FIG. 1

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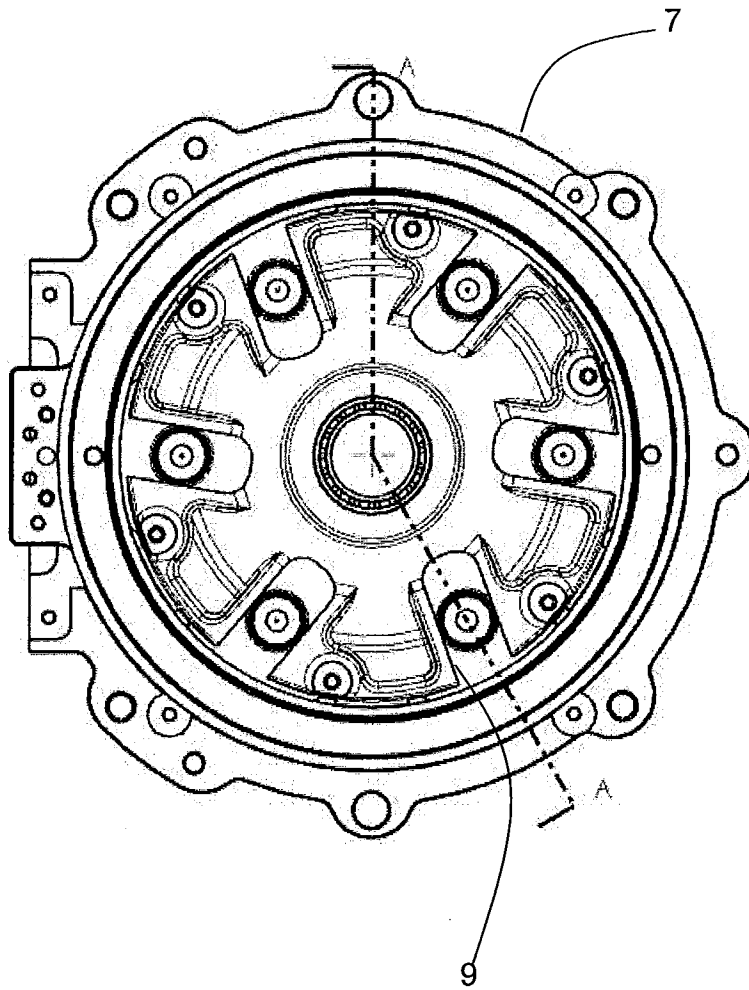


FIG. 2

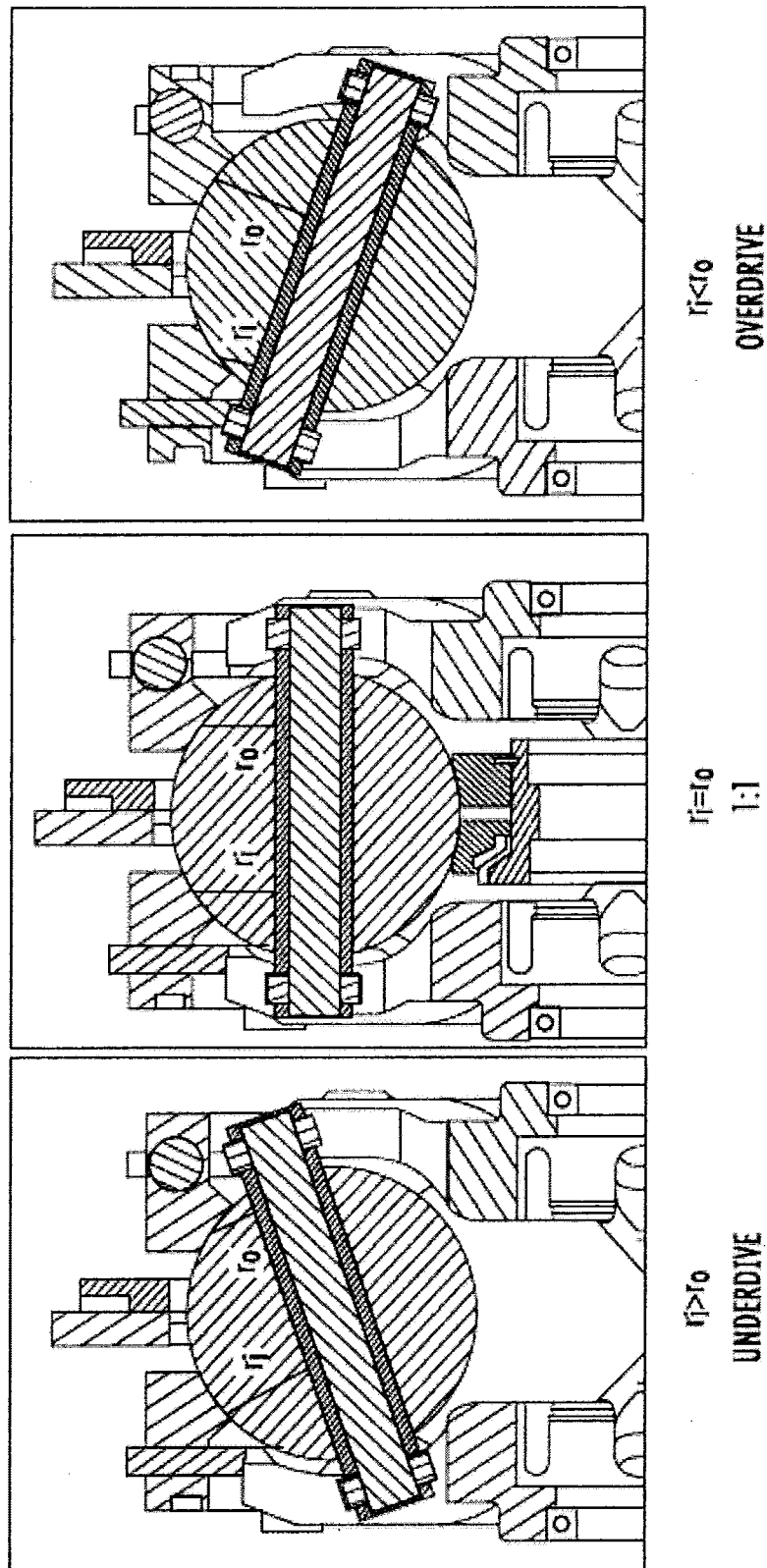


FIG. 3

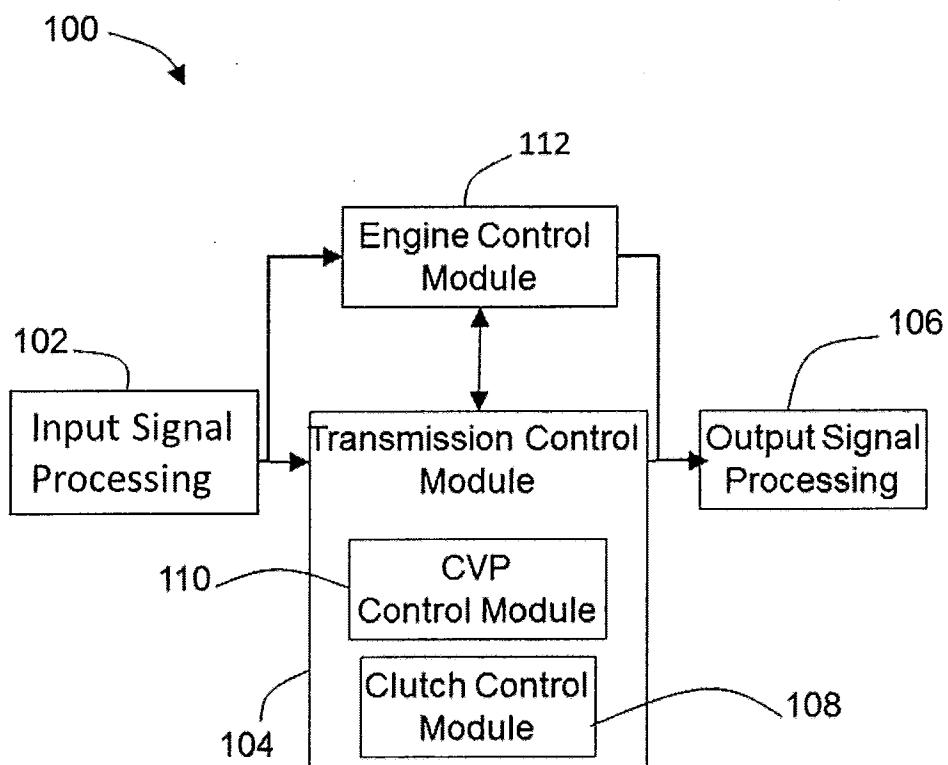


FIG. 4

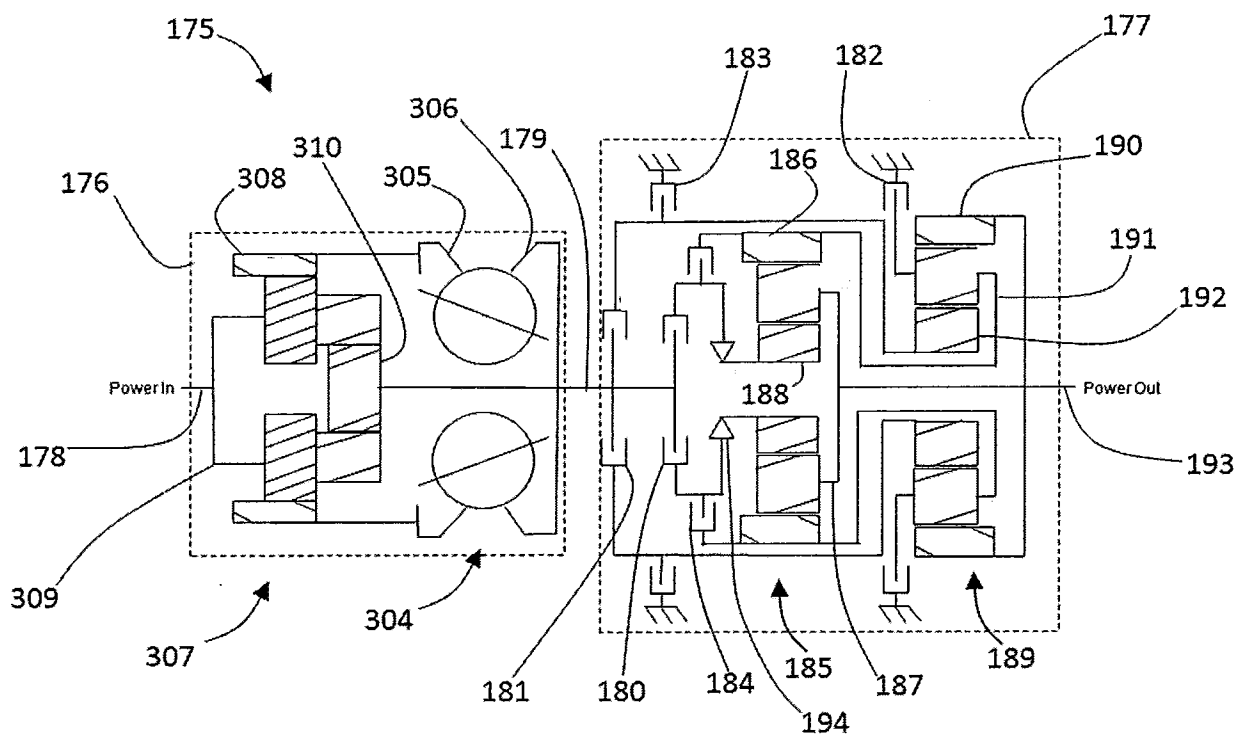


FIG. 5

	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		

FIG. 6

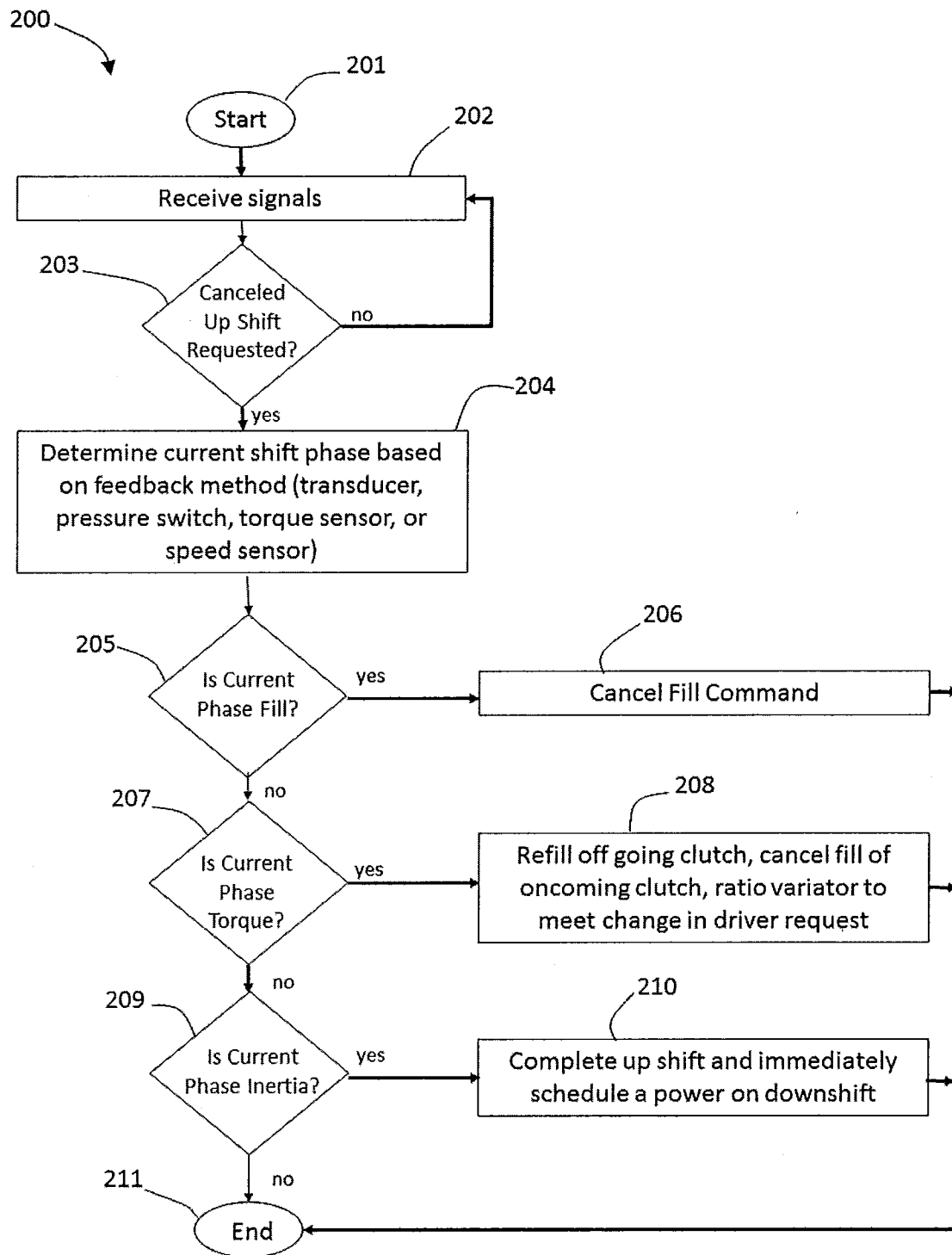


FIG. 7

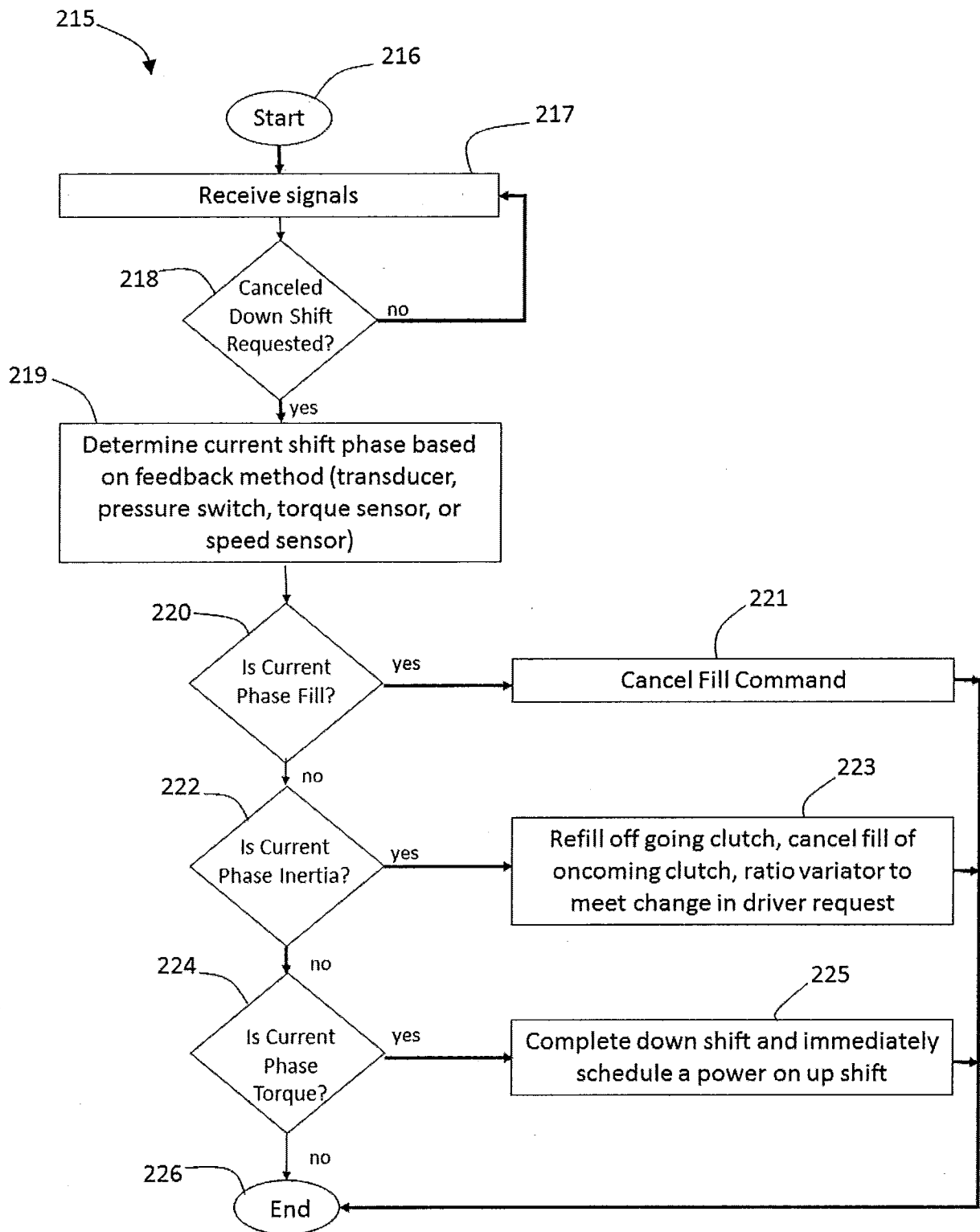


FIG. 8

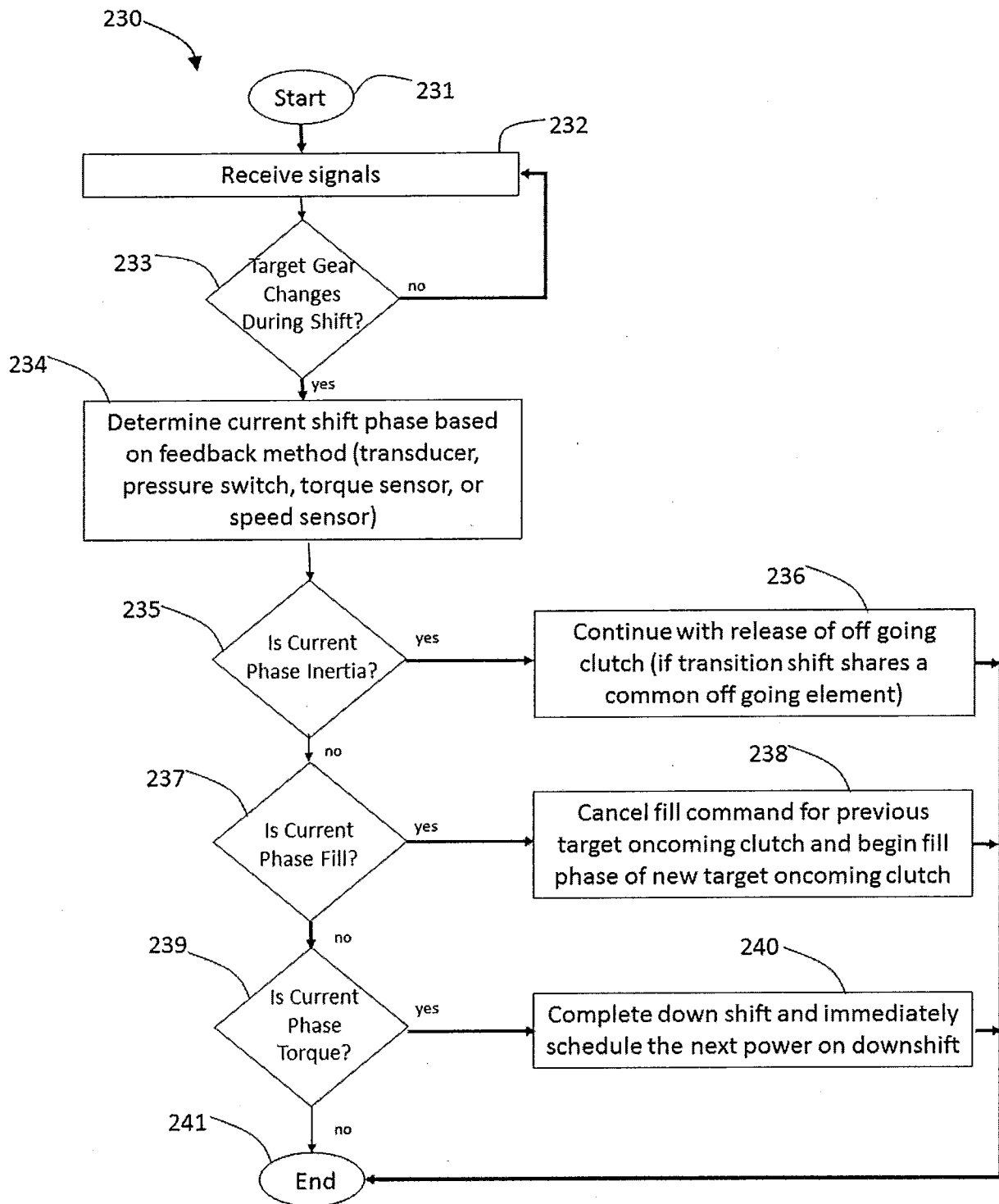


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/018268

A. CLASSIFICATION OF SUBJECT MATTER

INV. F16H61/04 F16H61/06 F16H61/664
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F16H

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	EP 0 341 631 A2 (HONDA MOTOR CO LTD [JP]) 15 November 1989 (1989-11-15) abstract; figures 5-7 column 3, line 36 - column 4, line 27 column 11, line 28 - column 16, line 9 -----	1-7
Y	US 2008/070748 A1 (TOKURA TAKAAKI [JP] ET AL) 20 March 2008 (2008-03-20) abstract; figures 1-3,6,9,10 paragraphs [0007], [0008], [0034] - [0044] ----- -/--	1-3



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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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

"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

20 April 2018

Date of mailing of the international search report

02/05/2018

Name and mailing address of the ISA/

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Authorized officer

Daïeff, Bertrand

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/018268

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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International application No

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