(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
20 November 2014 (20.11.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/186732 A1

(51) International Patent Classification:
F16H 13/00 (2006.01)

(21) International Application Number:
PCT/US2014/038439

(22) International Filing Date:
16 May 2014 (16.05.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/824,602 17 May 2013 (17.05.2013) US

(71) Applicant: **DANA LIMITED** [US/US]; P.O. Box 1000, Maumee, OH 43537 (US).

(72) Inventor: **PHILLIPS, Andrew, W.**; 4130 Holly Lane, Rochester, MI 48306 (US).

(74) Agent: **HAVRANEK, Kristin**; Wilson Sonsini Goodrich & Rosati, 650 Page Mill Road, Palo Alto, CA 94304 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

[Continued on next page]

(54) **Title**: 3-MODE FRONT-WHEEL DRIVE CONTINUOUSLY VARIABLE PLANETARY TRANSMISSION WITH STACKED GEARSETS

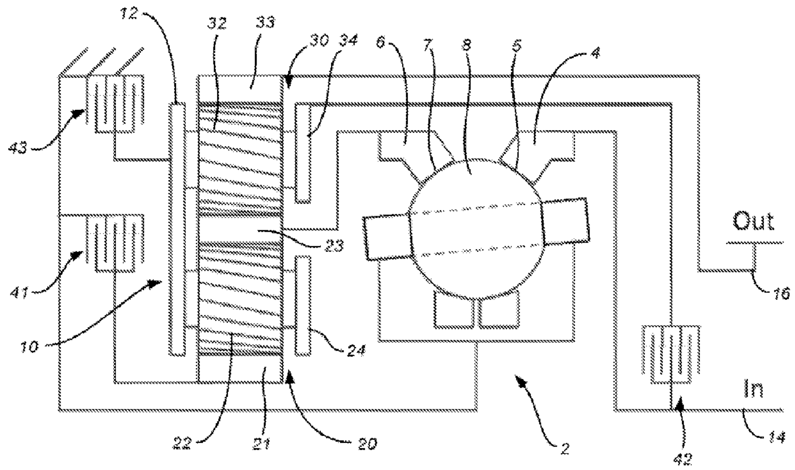

FIG. 1: 3-Mode CVP Transmission With Stacked Gearsets

(57) **Abstract**: A continuously variable transmission is provided having an input shaft, an output shaft, a continuously variable tilting ball planetary variator, two simple planetary gearsets forming a compound planetary gearset assembly and a plurality of torque transmitting devices. The transmission provided herein may be used for either front- wheel drive or rear drive applications, but is most advantageous for axially short front-wheel designs. The continuously variable transmission and the radially stacked simple planetary gearsets creating the compound gearset assembly described herein, have particular utility when utilized for axially short front-wheel drive designs.

WO 2014/186732 A1

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

3-MODE FRONT-WHEEL DRIVE CONTINUOUSLY VARIABLE PLANETARY TRANSMISSION WITH STACKED GEARSETS

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] The present application claims the benefit of U.S. Provisional Patent Application No. 61/824,602, filed May 17, 2013 which application is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] A vehicle having a driveline including a continuously variable transmission allows an operator of the vehicle or a control system of the vehicle to vary a drive ratio in a stepless manner, permitting a power source of the vehicle to operate at its most efficient rotational speed. Transmissions are becoming more complicated since the engine speed must be more precisely controlled to limit the fuel consumption and emissions of cars. Additionally transmission size is equally important. Recently, continuously variable transmissions have been proposed to provide continuously variable speed transmission speed ratios for vehicles having axially short designs.

SUMMARY OF THE INVENTION

[0003] Provided herein is a variable transmission comprising an input shaft, a tilting ball variator comprising an input ring, an output ring, a plurality of tilting variator balls, wherein the input ring is drivingly engaged to the input shaft; a compound planetary gearset assembly comprising two simple planetary gearsets wherein, a first simple planetary gearset comprising a first sun gear, a plurality of inner planet gears that are carried by an inner planetary carrier, and engage a common ring/sun gear; a second simple planetary gearset radially stacked on top of the first simple planetary gearset, comprising said common ring/sun gear, a plurality of outer planet gears that are carried by an outer planetary carrier, and engage an outer ring, wherein the inner planetary gear carrier and the outer planetary gear carrier are fixed together creating a joint planetary gear carrier; wherein the output of the tilting ball variator is drivingly engaged to the ring/sun gear, a first forward grounding clutch configured to selectively engage and rotationally fix the inner sun gear to the transmission case; a third reverse grounding clutch configured to selectively engage and rotationally fix the joint planetary gear carrier to the transmission case, a second forward clutch configured to selectively engage the input shaft to the joint planetary gear carrier and an output shaft drivingly engaged to the outer ring gear of the compound planetary gearset assembly. In some embodiments, the variable transmission comprises a ring gear of the first simple planetary gearset and the sun gear of the second simple planetary gearset formed as a unitary ring/sun gear having an outer surface and an inner surface, wherein the inner surface has a plurality of teeth and the outer surface has a plurality of teeth, and the inner surface of the unitary ring/sun gear meshes with the plurality of inner planet gears rotatably supported by the inner planet gear carrier of the first simple planetary gearset and the outer surface of the unitary ring/sun gear meshes a plurality of outer planet gears rotatably supported by the outer planetary gear carrier of the second simple planetary gearset. In some embodiments, the variable drive transmission comprises a first forward mode wherein engagement of the first grounding clutch to the inner sun gear fixes the rotation of the inner sun gear to the transmission case, thereby providing an approximate 2:1 mechanical advantage between the variator output and the transmission output. In some embodiments, the variable transmission comprises a second forward mode wherein the engagement of the second clutch drivingly engages the joint planetary gear carrier. In this mode, the transmission output speed ratio increases as the variator speed ratio decreases. For most of the speed range covered by this mode, the power through the variator is less than input power, so the transmission overall is more efficient. This is especially true as the transmission speed ratio reaches its upper limit, at (e.g.) a highway cruising operating point. In some embodiments, the variable transmission further comprises a reverse mode wherein the engagement of the reverse grounding clutch fixes the joint planetary carrier of the compound planetary gear set to the transmission case, reversing the direction of rotation of the output shaft. In some embodiments, the variable transmission further comprises an alternate and optional third clutch configured to selectively connect any two elements of the compound planetary gearset, causing the entire gearset to rotate as a single unit, and thus causing the transmission output speed to be equal to the variator output speed. Like the first forward mode and reverse mode, this optional mode passes all of the input power through the variator, making the system generally less efficient than the second forward, mode, but allows higher transmission output speed ratios. In one embodiment, an alternate third clutch selectively simultaneously engages the ring/sun gear and the first sun gear to create the lowest clutch torque requirement. In some embodiments the drivetrain is configured for a front-wheel drive vehicle. In some embodiments the drivetrain is configured for an axially short front-wheel drive vehicle. In some embodiments the drivetrain is configured for a rear-wheel drive vehicle.

Provided herein is a variable transmission comprising a stationary housing, an input shaft, an output shaft, a compound planetary gearset having first, second, third, and fourth rotating elements, a variator assembly having first and second rotating elements and three selectable torque transmitting devices wherein the input shaft is fixedly connected to the first rotating element of the variator assembly, the second rotating element of the variator is fixedly connected to the first rotating element of the compound planetary gearset, the output shaft is fixedly connected to the third rotating member of the compound planetary gearset; a first clutch causes the fourth rotating element of the compound planetary gear set to stop rotating, or in other words, grounding one end of the four-node lever and providing approximately 2:1 mechanical advantage between the variator output and the transmission output and, establishing a first forward mode variable range of overall transmission speed ratios; a second clutch selectively engages the input shaft to the second rotating element of the compound planetary gearset to establish a second forward mode variable range of overall transmission speed ratios by splitting power between a direct input and the variator; a reverse braking clutch selectively engages the second rotating element of the compound planetary gearset to ground, reversing the direction of rotation of the output shaft, establishing a reverse variable range of overall transmission speed ratios, and the variator establishes a controlled variable ratio between the speeds of its first and second rotating elements, thereby adjusting the overall transmission speed within any of the said variable ranges. In some embodiments of the variable transmission, the first clutch engages the fourth rotating element of the compound planetary gearset to ground, the second clutch engages the input shaft to the second rotating element of the compound planetary gearset, and the third rotating element of the compound planetary gearset is fixedly connected to the output shaft. In some embodiments of the variable transmission, the first clutch engages the fourth rotating element of the compound planetary gearset to ground, the alternate third clutch connects any two of the compound planetary gearsets four rotating elements, causing all of them to rotate at a common speed, creating a pure continuously variable planetary transmission range through the variator. In some embodiments of the continuously variable transmission, the first, second, third, and fourth elements of the compound planetary gearset are a ring/sun gear, a joint planetary gear carrier, an outer ring gear, and an inner sun gear, respectively. In some embodiments of the variable transmission, the variator is a tilting ball type variator comprising a carrier assembly rotatably supporting a set of pivoting axles rotatably disposed about the transmission axis, said axles each further rotatably supporting a ball; and first and second ring assemblies, each comprising a ball contact area in continuous contact with all of said balls, and wherein the first rotating element of the variator is said first ring assembly; the second rotating element of the variator is said second ring assembly; the carrier assembly moves in controlled fashion through a small range of angles with respect to the variator housing in order to cause the pivoting axles to change orientation, thus changing the speed ratio between said first and second ring assemblies, and the housing is fixed rotationally. In some embodiments of the variable transmission, the variator speed ratio between the first and second assembly rings increases; the overall transmission speed ratio within the first forward range increases; the overall transmission speed ratio within the second forward range decreases; the overall transmission speed ratio within the third alternate forward range increases; and the overall transmission speed ratio within the reverse range becomes more negative.

INCORPORATION BY REFERENCE

[0004] 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

[0005] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

[0006] Figure 1 is a stick diagram of an embodiment of the 3-mode transmission with stacked gearsets as described herein;

[0007] Figure 2 is a lever diagram corresponding to Figure 1;

[0008] Figure 3 is a graph of the transmission speed ratio on the X axis and the variator speed ratio on the Y axis, in accordance with embodiments described herein, in accordance with an embodiment of the 3-mode transmission with stacked gearsets as described herein;

[0009] Figure 4 is a side sectional view of a ball-type variator;

[0010] Figure 5 is a magnified, side sectional view of a ball of a variator of Figure 1 having a symmetric arrangement of a first ring assembly and a second ring assembly.

DETAILED DESCRIPTION OF THE INVENTION

[0011] The continuously variable transmission speed ratio can have the advantage of providing a smoother and continuous transition from a low speed ratio to a high speed ratio. However, the prior continuously variable transmissions can be more complex than would be ideal.

[0012] Continuously Variable Transmissions or CVTs are of many types: belts with variable pulleys, toroidal, and conical, for non-limiting example. The principle of a CVT is that it enables the engine to run at its most efficient rotation speed by changing steplessly the transmission ratio in function of the speed of the car and the torque demand (throttle position) of the driver. If needed, for example when accelerating, the CVT is configured to also shift to the most optimum ratio providing more power. A CVT is configured to change the ratio from the minimum to the maximum ratio without any interruption of the power transmission, as opposed to the opposite of usual transmissions which require an interruption of the power transmission by disengaging to shift from one discrete ratio to engage the next ratio.

[0013] Provided herein are configurations of CVTs based on a ball type variators, also known as CVP, for constant variable planetary. Some general aspects of the CVTs and CVPs are described in US20040616399 or AU2011224083A1, incorporated herein by reference in their entirety.

[0014] The type of CVT provided herein comprises a variator 2 comprising a plurality of variator balls 8, depending on the application, two discs or annular rings (input ring 4, output ring 6) each having an engagement portion 5, 7 that engages the variator balls 8. The engagement portions 5, 7 are optionally in a conical or toroidal convex or concave surface contact with the variator balls 8, as input and output. The variator optionally includes an idler contacting the balls as well as shown on either FIG. 1 or 4. The variator balls 8 are mounted on axes, themselves held in a cage or carrier allowing changing the ratio by tilting the variator balls' axes. Other types of ball CVTs also exist, like the one produced by Milner, but are slightly different. These alternative ball CVTs are additionally contemplated herein. The working principle generally speaking, of a ball-type variator (i.e. CVP) of a CVT is shown in FIG. 5.

[0015] As shown in FIG.4, a variator is a system that uses a set of rotating and tilting balls in a carrier that is positioned between an input ring and an output ring. Tilting the balls changes their contact diameters and varies the speed ratio. Contacting a rotating sphere at two different locations relative to the sphere's rotational axis will provide a "gear ratio", which can range from underdrive to overdrive depending on the location of the contact points for input and output torque and speed. As a result, the variator system offers continuous transition to any ratio within its range. The gear ratio is shifted by tilting the axes of the spheres in a continuous fashion, to provide different contact radii, which in turn drive the input and output rings, or discs.

[0016] The variator, as noted above, has multiple balls 8 to transfer torque through multiple fluid patches. The balls are placed in a circular array around a central idler (sun) and contact separate input and output traction rings 4, 6 engagement portions 5, 7. This configuration allows the input and output to be concentric and compact. The result is the ability to sweep the transmission through the entire ratio range smoothly, while in motion, under load, or stopped.

[0017] A traction fluid is optionally located in the variator for lubrication and traction. When this fluid undergoes high contact pressures under rolling contact between the two very hard elements, the balls and the rings, the fluid undergoes a near-instantaneous phase transition to an elastic solid. This is also known as elastohydrodynamic lubrication (EHL). Within this patch of traction the molecules of the fluid stack up and link to form a solid, through which shear force and thus torque can be transferred. Note that the rolling elements are actually not in physical contact when the elements are rotating.

[0018] The variator 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 first ring assembly (input of the variator), through the variator balls, to the second ring assembly (output of the variator). By tilting the variator balls' axes, the ratio is changed between input and output. When the axis of each of the variator balls is horizontal the ratio is one, when the axis is tilted the distance between the axis and the contact point change, modifying the overall ratio, between underdrive and overdrive. All the variator balls' axles are tilted at the same time and same angle with a mechanism included in the cage.

[0019] The embodiments of the present invention as described herein will find many applications. For example, although reference is made to vehicular applications, the continuously variable transmission as described herein can be used in many applications such as bicycles, motorized vehicles, wind turbines, and power tools, for example.

[0020] The embodiments of the present invention as described herein will find applications in front-wheel drive or rear-wheel drive transmission. In particular, the radially stacked simple planetary gearsets of the compound planetary gearset assembly described herein will be most advantageous for axially short, front-wheel drive transmission designs. When compared to other potential designs with the same number of modes, the single plane of stacked gears in this transmission, when compared to multi-level, multi-plane gear stacks of more traditional planetary gearsets creates a shorter, more compact package, better suited for smaller vehicles having minimal axial lengths, particularly front-wheel drive vehicles such as vehicles having transversely mounted / front-wheel drive transmissions.

[0021] The stacked configuration of the compound planetary gearset assembly 10 described herein, has a ring gear 23 from the inner simple planetary gearset 20, which also serves as the sun gear 23 of the outer simple planetary gearset 30, (alternatively called a ring/sun gear 23 herein). (The ring/sun gear may also be referred to as a "common", or "unitary" ring/sun gear hereinafter). Additionally, the planetary gear carriers of both simple planetary gearsets 24, 34, are fixed together, creating a joint planetary gear carrier 12, allowing the planet gears 22, 32, to be aligned radially, minimizing hoop stresses on the joint ring/sun gear 23.

[0022] Provided herein are embodiments of variable transmission configurations that include a variator 2 (alternatively called a CVP herein, such as a tilting-ball type variator), a compound planetary gearset assembly 10, comprising two radially stacked simple planetary gearsets 20, 30, a first forward grounding clutch 41, a second forward clutch 42, and a reverse grounding clutch

43. The embodiments depicted, and obvious variants to one of skill in the art upon reviewing the disclosure herein, provide a 3-Mode operation, a first forward mode, and a second forward mode of operation, at least, as well as a reverse mode.

[0023] In some embodiments, the variable transmission includes a first forward mode, wherein the engagement of the first grounding clutch 41 grounds the inner sun 21 of the first simple planetary gearset 20 and redirects a portion of the input shaft power from the tilting ball variator 2 to the joint planetary gear carrier 12, thereby allowing increased output shaft speed when the tilting ball variator output is increased, and providing an approximate 2:1 mechanical advantage between the variator output and the transmission output.

[0024] In some embodiments, the variable transmission includes a second forward mode, wherein disengagement of the of the first grounding clutch 41 releases the first sun gear 21, and the engagement of the second forward mode clutch 42 engages the joint planetary gear carrier 12, splitting power between a direct input and the variator. In doing so a portion of the input shaft power from the tilting ball variator 2 is redirected to the joint planetary gear carrier 12, thereby allowing increased output shaft speed relative to the first drive mode when the tilting ball variator output is decreased. In this mode, the transmission output speed ratio increases as the variator speed ratio decreases. For most of the speed range covered by this mode, the power through the variator is less than input power, and so the transmission overall is more efficient. This is especially true as the transmission speed ratio reaches its upper limit, at (e.g.) a highway cruising operating point.

[0025] In some embodiments, the variable transmission comprises a reverse grounding clutch 43 that selectively grounds the joint planetary carrier 12 to the transmission case; and a reverse mode wherein engagement of the reverse clutch 43 directs input shaft power through the tilting ball variator 2 and the ring/sun gear 23, thereby reversing the direction of the output shaft 16 being driven by the outer ring gear 33.

[0026] In some embodiments, the variable transmission comprises an optional / alternate third clutch 44, as shown in FIG. 2, wherein the optional third clutch 44 engages any two components of the compound gearset assembly 10, causing the entire gearset to rotate as a single unit, and thus transmission output speed to be equal to the variator output speed, extending the transmission overall ratio, and passing all of the input power through the variator to the ring/sun gear in a pure CVP range between 0.5 and 1.8. Like the first forward and reverse modes, this optional third mode passes all of the input power through the variator, so it is not generally as efficient as the second mode, but allows higher transmission output speed ratios.

[0027] An alternative embodiment of the variable transmissions provided herein comprises a variator 2, a compound planetary gearset assembly 10, comprising two radially stacked simple planetary gearsets 20, 30, a first forward grounding clutch 41, a second forward clutch 42, a reverse grounding clutch 43, and an optional, alternative third mode clutch 44 which can extend the transmission overall ratio, by connecting any two elements of the compound planetary gearset assembly 10, causing the entire gearset to rotate as a single unit and at a common speed, generating a transmission output speed equal to the variator output speed, thus creating a pure continuously variable planetary transmission range through the variator.

[0028] The compound planetary gearset assembly of FIG. 1 comprises two simple planetary gearsets 20, 30, radially stacked on top of each other, having a first simple planetary gearset 20 comprising a first sun gear 21, a plurality of inner planet gears 22 that are carried by an inner planetary carrier 24, and engage a common ring/sun gear 23, having an outer surface and an inner surface, wherein the inner surface has a plurality of teeth and the outer surface has a plurality of teeth, and the inner surface of the common ring/sun gear 23 meshes with the plurality of inner planet gears 22 rotatably supported by the inner planet gear carrier 24 of the first simple planetary gearset 20; a second simple planetary gearset 30 radially stacked on top of the first simple planetary gearset 20, comprising said common ring/sun gear 23, wherein the plurality of teeth on the outer surface of the unitary ring/sun gear 23 meshes with a plurality of outer planet gears 32 rotatably supported by an outer planetary gear carrier 34 of the second simple planetary gearset 30, and engage an outer ring gear 33, wherein the inner planetary gear carrier 24 and the outer planetary gear carrier 34 are fixed together creating a joint planetary gear carrier 12.

[0029] The variable planetary transmission represented by the 4-node lever diagram of FIG. 2 illustrates a 3-Mode CVT having an input shaft 14, an output shaft 16, a compound planetary gearset assembly 10 having first 23, second 12, third 33, and fourth 21 rotating elements, a variator assembly 2 having first and second rotating elements 4, 6, (not shown in this figure) and three selectable torque transmitting devices 41, 42, 43, wherein the input shaft 14 is fixedly connected to the first rotating element of the variator assembly 2, the second rotating element of the variator is fixedly connected to the first rotating element 23 of the compound planetary gearset 10, the output shaft 16 is fixedly connected to the third rotating member 33 of the compound planetary gearset 10; wherein when a first grounding clutch 41 is engaged, causing the fourth rotating element 21 of the compound planetary gear 10 set to stop rotating, thereby grounding one end of the four-node lever and providing an approximate 2:1 mechanical advantage between the variator output and the transmission output, and establishing a first forward mode variable range of overall transmission speed ratios; a second clutch 42 selectively engages the input shaft 14, , splitting power between second rotating element 12 of the compound planetary gearset 10 and the variator 2 to establish a second forward mode variable range of overall transmission speed ratios; a reverse grounding clutch 43 selectively engages the second rotating element 12 of the compound planetary gearset 10 to ground, reversing the direction of rotation of the output shaft, and establishing a reverse variable range of overall transmission speed ratios, and the variator establishes a controlled variable ratio between the speeds of its first and second rotating elements, thereby adjusting the overall transmission speed within any of said variable ranges.

[0030] The variable transmission illustrated in FIG. 2 further comprises an alternate, optional third clutch 44 configured to selectively connect any two elements of the compound planetary gearset assembly 10, causing the entire gearset to rotate as a single unit, at a common speed, and thus generating a transmission output speed equal to the variator output speed. Like the first forward and reverse modes, this optional third mode passes all of the input power through the variator 2, so it is not generally as efficient as the second mode, but allows higher transmission output speed ratios.

[0031] The rotating elements of the continuously variable transmission, include; a tilting ball type variator 2 comprising a carrier assembly rotatably supporting a set of pivoting axles rotatably disposed about the transmission axis, said axles each further rotatably supporting a ball 8; and first and second ring assemblies 4, 6, each comprising a ball contact area 5, 7, in continuous contact with all of said balls, and wherein the first rotating element of the variator is said first ring assembly 4; the second rotating element of the variator is said second ring assembly 6; and the first, second, third, and fourth elements of the compound planetary gearset assembly 10 which are a ring/sun gear 23, a joint planetary gear carrier 12, an outer ring gear 33, and an inner sun gear 21, respectively.

[0032] Additionally, a first grounding clutch 41 causes the fourth rotating element 21 of the compound planetary gear set 10 to stop rotating, establishing a first forward mode variable range of overall transmission speed ratios; a second clutch 42 selectively engaging the input shaft 14 to the second rotating element 12 of the compound planetary gearset 10, splitting power between a direct input and the variator 2, to establish a second forward mode variable range of overall transmission speed ratios: (For most of the speed range covered by this mode, the power through the variator is less than input power, so the transmission overall is more efficient. This is especially true as the transmission speed ratio reaches its upper limit, at (e.g.) a highway cruising operating point); a reverse grounding clutch 43 selectively engages the second rotating element 12 of the compound planetary gearset assembly 10 to ground, reversing the direction of rotation of the output shaft 16, establishing a reverse variable range of overall transmission speed ratios, and the variator 2 establishes a controlled variable ratio between the speeds of its first and second rotating elements, thereby adjusting the overall transmission speed within any of said variable ranges.

[0033] In some embodiments of the variable transmission, the first grounding clutch 41 engages the fourth rotating element 21 of the compound planetary gearset assembly 10 to ground, the second clutch 42 selectively engages the input shaft 14 to the second rotating element 12 of the compound planetary gearset 10, splitting power between a direct input and the variator 2, and the third rotating element 33 of the compound planetary gearset 10 is fixedly connected to the output shaft 16.

[0034] In further embodiments of the variable transmission, the alternate third clutch 44 connects any two of the compound planetary gearset assembly's four rotating elements 23, 12, 33, 21, causing the entire gearset assembly to rotate at a common speed, as a single unit, creating a pure continuously variable planetary transmission range through the variator 2, wherein the transmission output speed will be equal to the variator output speed.

[0035] In a preferred embodiment of the continuously variable transmission described herein, the radially stacked simple planetary gearsets creating the compound gearset assembly, have particular utility when utilized for axially short front-wheel drive designs because when compared to other potential designs with the same number of modes, the single plane of stacked gears in this transmission, when compared to multi-level, multi-plane gear stacks of more traditional planetary gearsets creates a shorter, more compact package, better suited for smaller vehicles having minimal axial lengths, particularly front-wheel drive vehicles such as vehicles having transversely mounted / front-wheel drive transmissions.

[0036] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

CLAIMS

WHAT IS CLAIMED IS:

1. A variable transmission comprising:

an input shaft;

a tilting ball variator comprising an input ring, an output ring, a plurality of tilting variator balls, wherein the input ring is drivingly engaged to the input shaft;

a compound planetary gearset assembly comprising;

two simple planetary gearsets wherein,

a first simple planetary gearset comprising a first sun gear, a plurality of inner planet gears that are carried by an inner planetary carrier, and engage a unitary ring/sun gear;

a second simple planetary gearset radially stacked in substantially a single plane on top of the first simple planetary gearset, comprising said unitary ring/sun gear, a plurality of outer planet gears that are carried by an outer planetary carrier, and engage an outer ring, wherein the inner planetary gear carrier and the outer planetary gear carrier are fixed together creating a joint planetary gear carrier; wherein

the output of the tilting ball variator is drivingly engaged to the ring/sun gear,

a first forward grounding clutch configured to selectively engage and rotationally fix the inner sun gear to the transmission case;

a third reverse grounding clutch configured to selectively engage and rotationally fix the joint planetary gear carrier to the transmission case,

a second forward clutch configured to selectively engage the joint planetary gear carrier; and

an output shaft drivingly engaged to the outer ring gear of the compound planetary gearset assembly.

2. The variable transmission of claim 1, wherein the ring gear of the first simple planetary gearset and the sun gear of the second simple planetary gearset is formed as a unitary ring/sun gear, having an inner surface and an outer surface, wherein the inner surface has a plurality of teeth and the outer surface has a plurality of teeth.

3. The variable transmission of claim 2, wherein the inner surface of the unitary ring/sun gear meshes with the plurality of inner planet gears rotatably supported by the inner planet gear carrier of the first simple planetary gearset and the outer surface of the unitary

ring/sun gear meshes a plurality of outer planet gears rotatably supported by the outer planetary gear carrier of the second simple planetary gearset.

4. The variable transmission of claim 1, wherein the housing of the variator is rotationally fixed.

5. The variable transmission of claim 1, wherein the drivetrain is configured for a front-wheel drive vehicle.

6. The transmission of claim 5, wherein the vehicle is an axially short front-wheel drive vehicle.

7. The variable transmission of claim 1, wherein the drivetrain is configured for a rear-wheel drive vehicle.

8. The variable transmission of claim 1, further comprising a first forward mode wherein engagement of the first grounding clutch to the inner sun gear fixes the rotation of said inner sun gear to the transmission case, providing a mechanical advantage between the variator output and the transmission output.

9. The variable transmission of claim 8, wherein the mechanical advantage is about 2:1.

10. The variable transmission of claim 1 further comprising a second forward mode wherein the engagement of the second clutch drivingly engages the joint planetary gear carrier.

11. The variable transmission of claim 10, wherein the input power is split between a direct input and the variator.

12. The variable transmission of claim 10, wherein the power through the variator is less than input power through most of the speed range.

13. A variable transmission of claim 1, further comprising a reverse mode wherein the engagement of the reverse grounding clutch fixes the joint planetary carrier of the compound planetary gear set to the transmission case, reversing the direction of rotation of the output shaft.

14. The variable transmission of claim 1, further comprising an optional third clutch configured to selectively connect any two elements of the compound planetary gearset, causing the entire gearset to rotate as a single unit, and at a common speed.

15. The variable transmission of claim 14, wherein the transmission output speed is equal to the variator output speed.

16. The variable transmission of claim 14, wherein the output is a pure continuously variable planetary transmission range through the variator.

17. The variable transmission of claim 11, wherein the alternate third clutch selectively simultaneously engages the ring/sun gear and the first sun gear to create the lowest clutch torque requirement.

18. A variable transmission comprising;

a stationary housing;

an input shaft;

an output shaft;

a compound planetary gearset having first, second, third, and fourth rotating elements;

a variator assembly having first and second rotating elements; and three selectable torque transmitting devices;

wherein the input shaft is fixedly connected to the first rotating element of the variator assembly;

the second rotating element of the variator is fixedly connected to the first rotating element of the compound planetary gearset;

the output shaft is fixedly connected to the third rotating member of the compound planetary gearset;

a first clutch selectively engages the fourth rotating element of the compound planetary gear set to the transmission case, establishing a first forward mode variable range of overall transmission speed ratios;

a second clutch selectively engages the input shaft to the second rotating element of the compound planetary gearset to establishing a second forward mode variable range of overall transmission speed ratios;

a reverse clutch selectively engages the second rotating element of the compound planetary gearset to ground establishing a reverse variable range of overall transmission speed ratios, and

the variator establishes a controlled variable ratio between the speeds of its first and second rotating elements, thereby adjusting the overall transmission speed within any of said variable ranges.

19. The transmission of claim 18, wherein an alternate third clutch engages any two of the compound planetary gearsets four rotating elements, causing all of them to rotate at a common speed, generating a pure continuously variable planetary transmission range through the variator.

20. The transmission of claim 18, wherein the first, second, third, and fourth elements of the compound planetary gearset are a ring/sun gear, a joint planetary gear carrier, an outer ring gear, and an inner sun gear, respectively.

21. The transmission of claims 18 – 20, wherein the compound planetary gearset comprises;

a first simple planetary gearset comprising a first sun gear, a plurality of inner planet gears that are carried by an inner planetary carrier, and engage a unitary ring/sun gear;

a second simple planetary gearset radially stacked substantially on top of the first simple planetary gearset, comprising said unitary ring/sun gear, a plurality of outer planet gears that are carried by an outer planetary carrier, and engage an outer ring, wherein the inner planetary gear carrier and the outer planetary gear carrier are fixed together creating a joint planetary gear carrier; and

wherein said first rotating element of the compound planetary gearset is said ring/sun gear;

the second rotating element of the compound planetary gearset is the joint planetary gear carrier;

the third rotating element of the compound planetary gearset is the outer ring gear; and

the fourth rotating element of the compound planetary gearset is the inner sun gear.

22. The transmission of claims 18 – 21, wherein the variator is a tilting ball type variator comprising;

a carrier assembly rotatably supporting a set of pivoting axles rotatably disposed about the transmission axis, said axles each further rotatably supporting a ball; and

first and second ring assemblies, each comprising a ball contact area in continuous contact with all of said balls, and

wherein the first rotating element of the variator is said first ring assembly;

the second rotating element of the variator is said second ring assembly;

the carrier assembly moves in controlled fashion through a small range of angles with respect to the variator housing in order to cause the pivoting axles to change orientation, thus changing the speed ratio between said first and second ring assemblies, and

said housing is fixed rotationally.

23. The transmission of claims 18 – 22, wherein, as the variator speed ratio between the first and second assembly rings increases,

the overall transmission speed ratio within said first forward range increases;

the overall transmission speed ratio within said second forward range decreases;

the overall transmission speed ratio within said third alternate forward range increases; and

the overall transmission speed ratio within said reverse range becomes more negative.

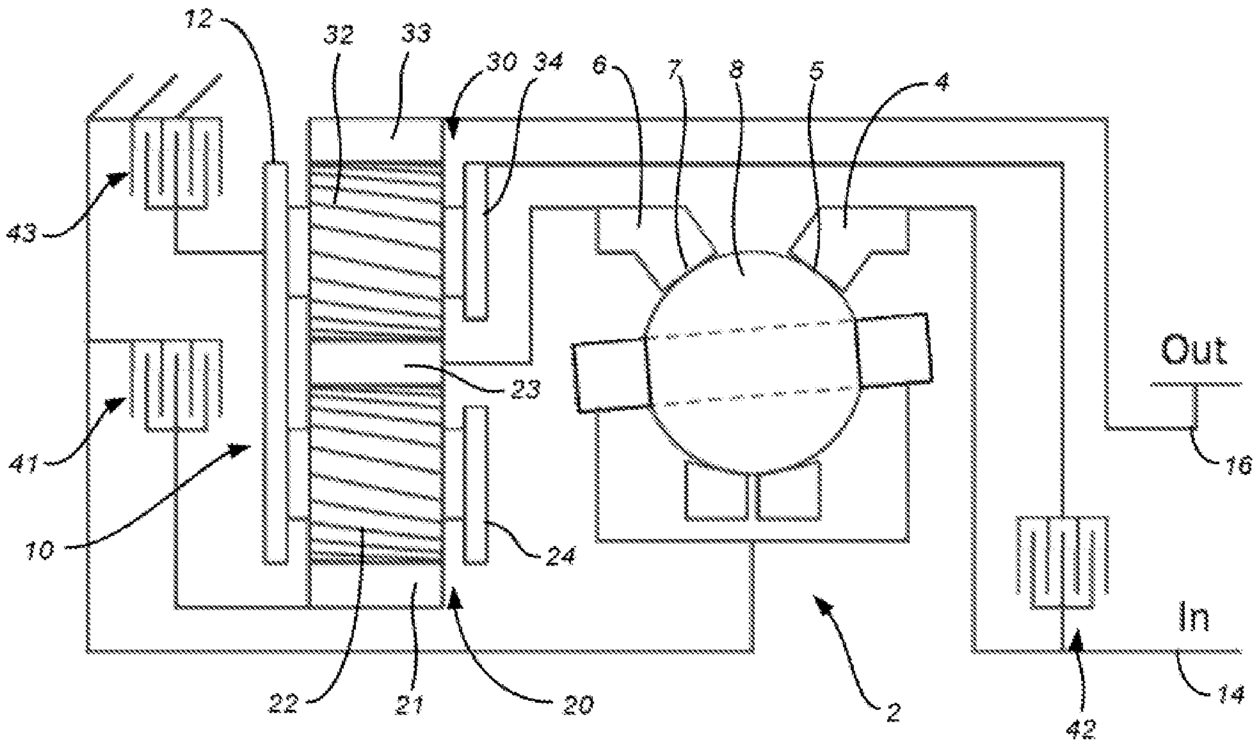

FIG. 1: 3-Mode CVP Transmission With Stacked Gearsets

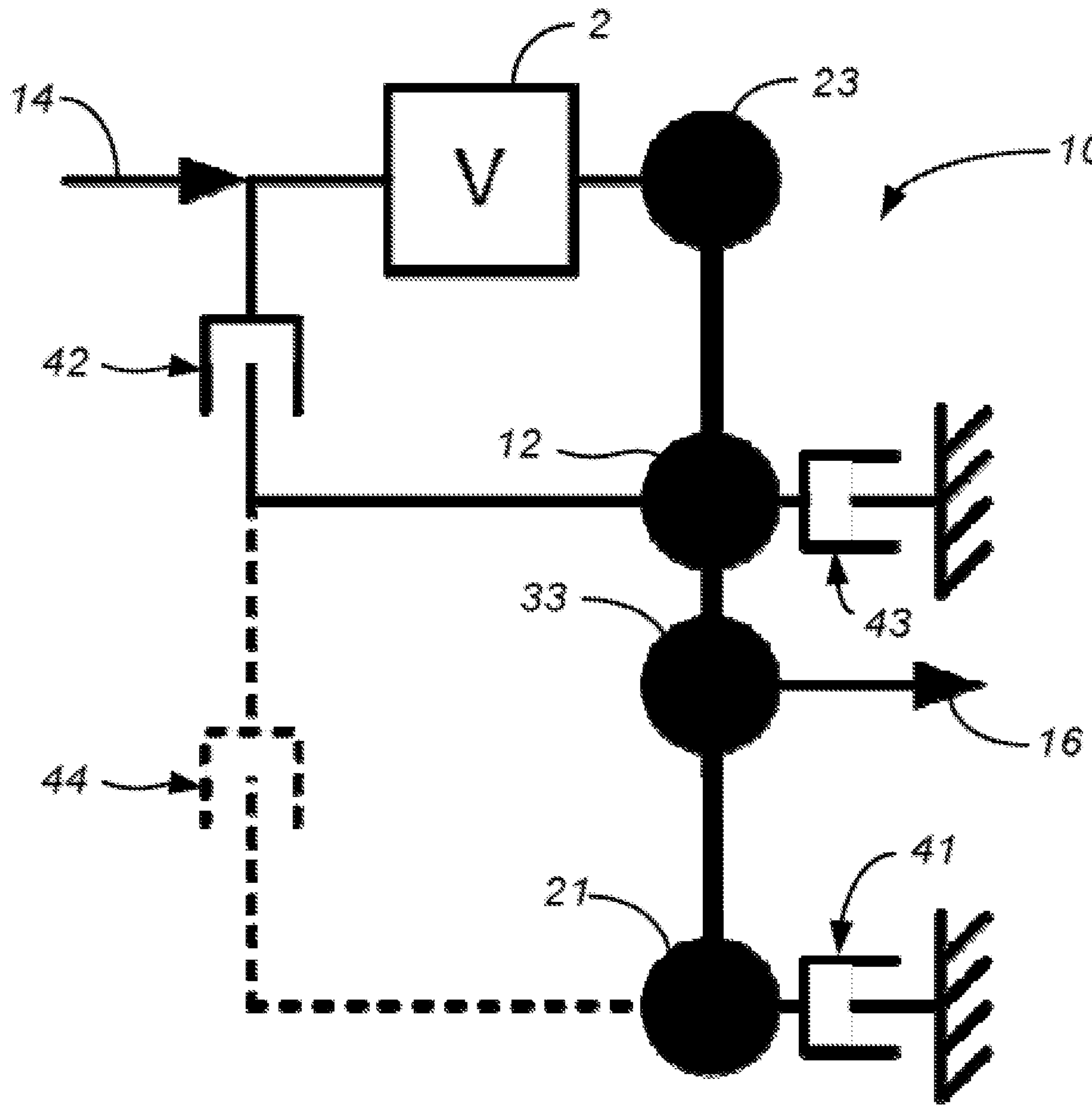

FIG. 2: Lever Diagram

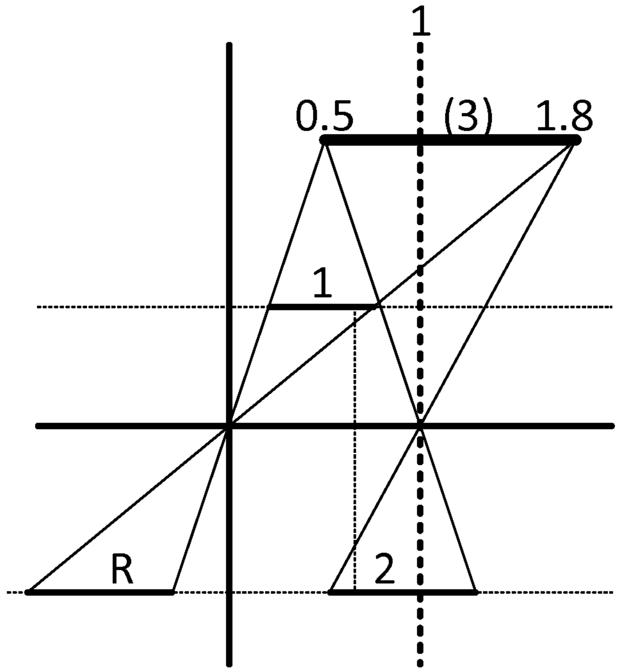

FIG. 3: Ratio Ranges

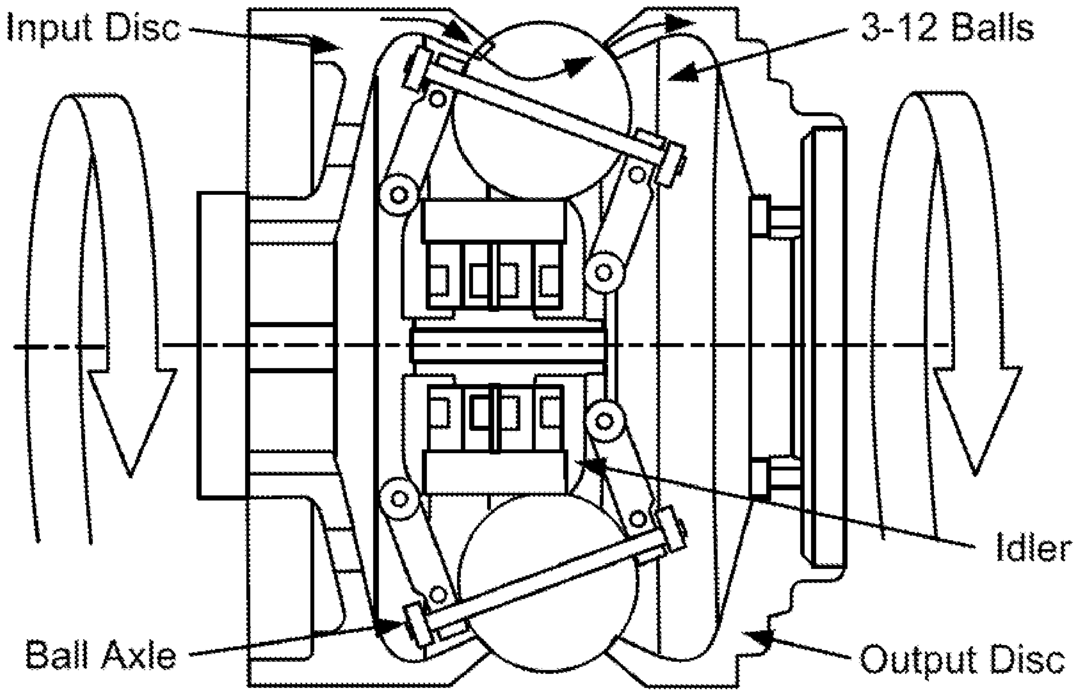

FIG. 4: Main Elements of the CVP

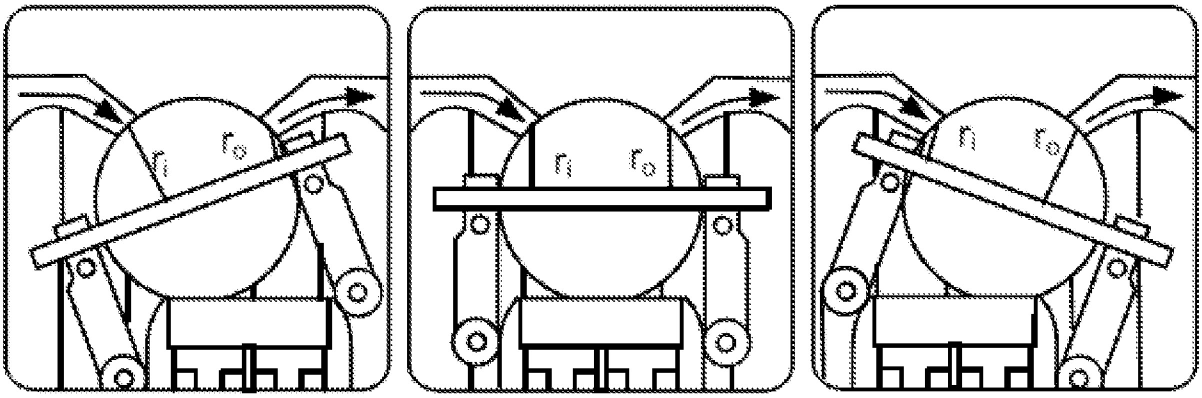

FIG 5: Ratio Change in the CVP

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/038439

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F16H 13/00 (2014.01)
CPC - F16H 13/08 (2014.09)
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)
IPC(8) - F16H 13/00, 13/12, 13/14, 15/40, 15/48, 15/50, 37/00, 37/12, 37/14 (2014.01)
CPC - F16H 13/00, 13/06, 13/08, 15/40, 15/48, 15/50, 37/00, 37/12, 37/128, 37/14 (2014.09)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 475/183-185, 189-192, 196, 197; 476/31-34, 36-38

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 8,313,404 B2 (CARTER et al) 20 November 2012 (20.11.2012) entire document	1-20
A	US 7,980,972 B1 (STARKEY et al) 19 July 2011 (19.07.2011) entire document	1-20
A	US 2012/0309579 A1 (MILLER et al) 06 December 2012 (06.12.2012) entire document	1-20

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"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	Date of mailing of the international search report
08 September 2014	30 SEP 2014

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/038439

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 21-23
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.