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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 November 2013 (28.11.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/175165 A1

(51) International Patent Classification:
B60K 6/10 (2006.01) *B60K 6/543* (2007.10)
B60K 6/445 (2007.10) *F16H 15/52* (2006.01)

(21) International Application Number:
PCT/GB2013/000242

(22) International Filing Date:
28 May 2013 (28.05.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

1209265.6	25 May 2012 (25.05.2012)	GB
1210112.7	8 June 2012 (08.06.2012)	GB
1212367.5	11 July 2012 (11.07.2012)	GB
1216511.4	17 September 2012 (17.09.2012)	GB

(71) Applicant: CITY UNIVERSITY [GB/GB]; Northampton Square, London EC1V 0HB (GB).

(72) Inventor: GASKELL, Christopher James; 62 Bargery Road, London SE6 2LW (GB).

(74) Agent: MILHENCH, Mark Lorne; First Thought IP Ltd., 35 New Broad Street House, New Broad Street, London EC2M 1NH (GB).

(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, 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, 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,

[Continued on next page]

(54) Title: VARIATOR

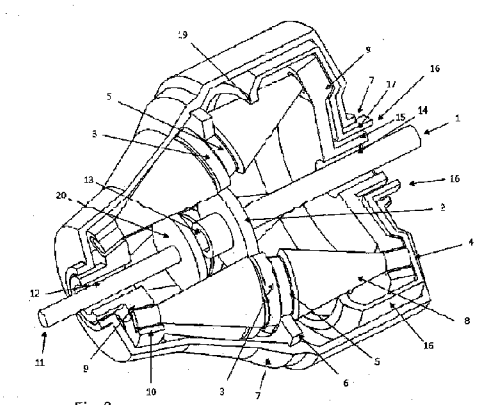


Fig. 2

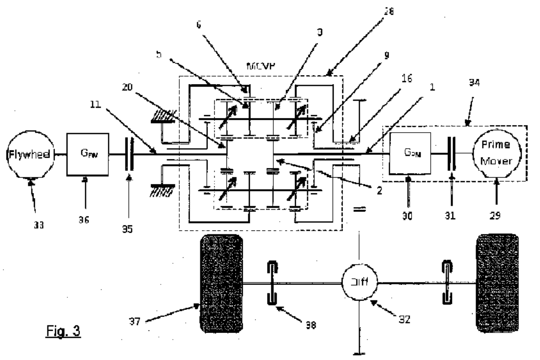


Fig. 3

(57) Abstract: A variator for a transmission system, the variator comprising: a first and a second cone, said cones being rotatable about a common axis that is inclined relative to a main axis so that said first and second cones each provide a contact surface that is substantially parallel to said main axis.

WO 2013/175165 A1

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).

Published:

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

VARIATOR

Field

This invention relates to variators, particularly but not exclusively to variators for transmission systems - for example, vehicle transmission systems. Other aspects of the present invention relate to transmission systems, to a propulsion system for a vehicle, and to a vehicle incorporating such a propulsion system.

This application claims priority from the following UK patent applications: GB1209265.6, GB1210112.7 and GB1212367.5; and the contents of each of these prior UK patent applications is incorporated herein by reference as though they were each reproduced in this document in full. Applicant's intention is that information should be freely transferrable between each of these applications.

A supplement accompanies this application, and that supplement provides further technical details of the arrangements described in this document. The accompanying supplement forms an integral part of this application, and information may be freely transferred between this application and the supplement, and vice versa.

Background

It appears likely that future engines in vehicles will probably need to be downsized (made to have fewer cylinders and smaller volumetric capacity) in order to reduce the internal frictional and pumping losses. Supercharging and/or turbocharging of downsized engines can enable them to provide the power of larger engines, and thereby meet the performance expectations of the customer whilst saving energy. Another method (which can be used simultaneously) is to provide a so-called "hybrid" system; an auxiliary propulsion system for the vehicle that can operate in conjunction with the engine or on its own to enable reduction in energy consumption and emissions by various methods (such as regenerative braking) and also the potential to increase vehicle performance.

Electric hybrid powertrains (using electrochemical batteries, power electronics and motor-generators) have previously been proposed, but such arrangements tend to be relatively expensive compared to traditional internal combustion engine powertrains. It is also the case that inefficiencies associated with the multiple conversions of energy into different forms that take place in such systems (particularly during regenerative braking) reduces the net amount of energy that can be saved with such a system as compared with a conventional vehicle. It is also the case that electric systems are typically relatively heavy and therefore extra energy is spent transporting this extra mass. Even though fully-electric vehicles will have zero "at the wheel" emissions, it is the case that manufacturing and subsequent end-of-life processing of electrochemical batteries for this application has significant environmental impact. In the light of this, it would be beneficial to provide hybrid systems that reduce the total energy consumption and emissions, that are fully-recyclable and that come at a price point that is affordable for manufacturer and customer alike. Previously proposed electric hybrids do not (at present) meet all of these criteria.

It has previously been proposed to use a flywheel as a kinetic energy storage device to provide a mechanical alternative to electrical systems. Previously proposed high-speed flywheel hybrid systems (such as those of Flybrid Automotive Ltd) generally have a higher power-to-weight ratio than equivalent electric hybrid systems and are able to capture and return more of a vehicle's kinetic energy when performing regenerative braking. This is mostly because energy form conversions are avoided, especially during regenerative braking; kinetic energy is simply transferred from one inertia to another (the vehicle and the energy storage flywheel). Mechanical transmissions are usually recyclable since they are constructed almost entirely from steel and aluminium (apart from the seals and lubricants and a carbon fibre wrap for the high-speed flywheel). The abundance of these materials means that the cost of the raw material is relatively low, and mass-manufacturing techniques allow relatively low-cost manufacture.

Previously proposed flywheel hybrid systems (such as those of Flybrid Automotive Ltd) are designed to interface with conventional vehicle architecture, comprising a clutch, discrete gearbox and differential. This is to provide a low-cost system that can be readily accepted by vehicle manufacturers mindful of financial risk, since it does not fundamentally change the layout and overall concept of the vehicle. Flybrid Automotive Ltd's current advertised systems are able to accomplish regenerative braking, function in engine stop-start mode (e.g. in a mode where the engine can be turned off while waiting at traffic lights) and drive the vehicle under flywheel power alone. In addition to these useful modes of operation, the flywheel can be used to allow the engine to operate in a more efficient regime than is normally possible with a discrete gearbox transmission alone. This is achieved by either subtracting surplus engine torque by charging the flywheel, or adding to insufficient engine torque by discharging the flywheel. Whilst these arrangements work well, it would be beneficial to provide flywheel technology that unifies the main vehicle transmission and the hybrid system so that additional useful modes of operation can be provided that enable further energy savings and reduce emissions.

Aspects of the present invention have been conceived with the foregoing in mind.

Summary

One illustrative aim of a particular embodiment of the present invention is to provide a mechanical hybrid powertrain (using a flywheel) that is integral to the main transmission and one that is able to operate in all modes of operation offered by electric hybrid vehicles that aid reduction in energy/fuel consumption. One particular advantage of an arrangement disclosed herein is that an engine (or other prime mover) can be run in an efficient mode of operation, fully isolated from the instantaneous power delivery requirements of the vehicle, rather like a series hybrid powertrain, sometimes known as an electric CVT (continuously variable transmission). In essence it is sometimes beneficial to be able to run the engine in a constant condition of lowest specific fuel consumption, independent of how the vehicle is driving. Such a function cannot be provided by previously proposed flywheel systems, including those of Flybrid Automotive Ltd. This is because such a function requires a form of mechanical CVT for the engine (or other prime mover) as well as that required for the flywheel.

One illustrative implementation of the teachings of this invention provides a mechanical CVT for the engine (or other prime mover) as well as a mechanical CVT for controlling energy storage and recovery of a flywheel (or other energy storage device).

Another illustrative advantage of the mechanical CVTs disclosed herein – as compared with electric CVT systems - is that energy form conversions are avoided; once fuel has been converted into mechanical energy at the engine crank (or energy stored in an electrochemical battery has been converted into mechanical energy at the motor-generator shaft), it remains in this state throughout the transmission. Additionally, the mechanical systems proposed herein will likely be less expensive and more recyclable than their electric alternatives.

In one aspect the teachings of the invention provide a continuously variable transmission that includes any combination of features disclosed in this application alone, or in combination with any features disclosed in any of the aforementioned priority applications or the accompanying supplement.

Other aspects of the invention relate to: a variator, a transmission system, and a propulsion system for a vehicle that includes such a transmission, and to a vehicle that includes such a propulsion system.

Further embodiments, features and advantages of aspects of the invention will be apparent from the following detailed description and the accompanying claims.

Description of the Drawings

Various aspects of the teachings of the present invention, and arrangements embodying those teachings, will hereafter be described by way of illustrative example with reference to the accompanying drawings, in which:

Fig. 1 is a schematic representation of a variator (elsewhere referred to as an MCVP) configuration for a first embodiment of the teachings of the invention;

Fig. 2 is a schematic cutaway view of the variator depicted schematically in Fig. 1;

Fig. 3 is a schematic transmission diagram for a first embodiment of the present invention;

Fig. 4 is a schematic transmission diagram for a second embodiment of the present invention;

Fig. 5 is a schematic representation of an illustrative geometry for an external mesh;

Fig. 6 is a schematic representation of an illustrative geometry for an internal mesh;

Fig. 7 is a schematic representation of a variator that may be configured for use as an infinitely variable transmission (IVT);

Fig. 8 is a schematic representation of another variator that may be configured for use as an IVT; and

Figs. 9 to 12 are schematic representations of various illustrative variator cone arrangements;

Detailed Description.

Various arrangements embodying the teachings of the present invention will now be described by way of illustrative example. Whilst the following arrangements are presented in numbered sections, this is merely for convenience and should not be construed as meaning that each arrangement is discrete from the others. Rather, it is the applicant's intention that subject matter from these embodiments should be freely combinable (both with other embodiments of this application and/or with material contained in the supplement and/or any of the priority applications).

It should further be noted that whilst the following description will refer to automotive applications, the teachings of the present invention are not limited to automotive applications and could instead be utilised in many other applications.

As is known in the art, continuously variable transmissions (CVTs) are those where the speed ratio of the transmission can be varied in a mathematically continuous manner between maximum and minimum values, differing from transmissions that can provide only a finite number of mathematically discrete ratios.

Infinitely variable transmissions (IVTs) are those where a "geared neutral" condition of zero output speed can be achieved within the range of maximum and minimum transmission ratios, where the input is still rotating and remains coupled to the stationary output. Continuously and infinitely variable transmissions are commonly used in such applications as vehicle primary and auxiliary transmissions, and industrial drives.

Variators are devices that can be used to provide a continuously variable transmission. The most common way of achieving an infinitely variable transmission is to couple a variator with differential gearing. However, certain variators have been previously proposed in configurations that provide an infinitely variable transmission without requiring any additional gearing [see for example WO 2011/109444 A1].

The particular variator described herein will hereafter be referred to as an MCVP, and other types of variator will simply be referred to as a variator.

1. Multi-Continuously Variable Planetary (MCVP) hybrid transmission (CVT/IVT)

This illustrative implementation of the teachings of the invention employs a novel multiple-input variator (referred to herein as an MCVP) with two independent ratio control mechanisms. The MCVP is a planetary transmission with multiple planets that are double conical surfaces whose rotational axes are inclined relative to the main variator rotational axis – in an envisaged arrangement at an angle equal to the half cone angle, as shown in **Error! Reference source not found.** below.

The general arrangement of an MCVP provides two surfaces that are parallel to the main axis. Axial shifting of a central disc 20 along an inside surface provides a sun branch with variable speed ratio; and axial shifting of an outer annulus along an outside surface provides a branch with variable speed ratio. The speed ratio is changed by virtue of changing the contact radius on the conical surfaces by axial shifting of a sun or annulus that contacts one of the said surfaces parallel to the main axis. The two variable branches in other arrangements may be two variable annuli (as depicted in Fig.12) or two variable suns (as depicted in Fig.12). The two variable branches of a particular MCVP configuration may be controlled independently of each other.

In addition to these two surfaces, there may be additional surfaces provided that correspond to branches with constant speed ratio, since the contact radius remains constant. The possible geometry of such surfaces is described in section 5.

The two variable branches may be coupled to two independent sources of motive power, or two independent power sinks (otherwise termed loads). For instance, a prime mover or a flywheel being discharged may be considered as sources of motive power. A vehicle driven axle or a flywheel being charged may be considered as power sinks or loads.

The arrangement shown in Fig.1 and Fig.2 provides two surfaces that are parallel to the main axis; one corresponds to a variable annulus, one corresponds to a variable sun. Axial shifting of a central disc 20 along the inside surface provides a sun branch with variable speed ratio to control the flywheel; and axial shifting of an outer annulus along the outside surface provides a branch with IVT functionality for example for the vehicle final drive.

Fig 2 is a schematic representation of a MCVP configured as in Figure 1 where the constant annulus branch is fixed to ground. The final drive of the vehicle is connected to the variable annulus shaft, which gives IVT potential (including reverse, with the bias of the ratio spread being chosen to suit the application by suitable design selection of the MCVP radii shown in Fig. 1).

In other embodiments, a different branch may be fixed to ground (such as the carrier 9, for example, corresponding to a CVT arrangement), or all branches may be rotatable (such as in section 3). Other embodiments that provide IVT functionality without any additional gearing are shown in section 6.

The MCVP arrangement shown in Fig. 2 uses planets where the cones face base to base on the planet shaft; this is also shown in Fig. 9. The two cones may also be arranged such that they may face tip to tip (as shown in Fig. 10) or in the same direction. The former arrangement would allow the diameter of the constant annulus to be reduced (which reduces the rotational stresses for the same shaft angular speed), the latter would mean that either both of the sun branches would be variable (as shown in Fig. 12) or both of the annuli branches would be variable (as shown in Fig. 11).

Generation of normal forces in the contact patches required for efficient torque transfer is not so straight forward in this embodiment, since the carrier is rotating (see also TurboTrac patents US6001042 and US7856902). Planets may be inclined at an angle that is deliberately greater or smaller than the half cone angle so that an increasing interference as the contact disc/annulus moves in a direction of increasing (steady state) torque (i.e. reduction in speed output shaft speed, and hence increase in torque for the same power). This is a passive system, meaning it does not require any external control. Another passive method would be elastically straining the disc/annulus that make traction contact with the conical planets, where this strain creates further interference and hence generates normal pressure on the fluid which increases with applied torque. The system may be bi-directional so that two similar mechanisms are used to act in opposite directions to create pressure from reversing torque. There would be backlash in this system as one mechanism relaxes whilst the other tenses when the direction of torque reverses.

A prime mover is connected to the constant sun shaft 1, to which is attached a bevel gear 2 (the constant sun gear) which meshes with a set of planet bevel gears 3 which are located in this arrangement at the axial centre of the planet 4 (one for each planet). Also on each planet 4 is another bevel gear 5 which meshes with an internal bevel gear 6, which is the constant annulus shaft (non-rotational in this arrangement since this branch is fixed to the casing 7). It will be appreciated by those experienced in the art that the bevel gears on the planets can be positioned in various places along the planet axis, such as between the cones 8 as shown or either side to achieve the same functionality and that the choice will ultimately be made by the constraints of the assembly. The planets are supported in a planet carrier 9 using bearings 10, said carrier being free to rotate in this arrangement, but may be used as an input/output shaft in another arrangement.

The input to the MCVP from the flywheel is connected to the variable sun shaft 11 which is supported by bearings 12, 13 in the carrier 9 and constant sun shaft 1 respectively. The constant sun shaft 1 may be supported by bearings 14 in the carrier 9 which is in turn supported by bearings 15 in the hollow variable annulus shaft 16. The variable annulus shaft 16 is geared to the final drive of the vehicle. The variable annulus shaft 16 is supported by bearings 17 in the casing 7. A beneficial feature of this arrangement is that all input/output shafts and the carrier rotate in the same direction and so the bearings only run at the difference between the shaft speeds, so the speed rating requirement for the bearings is not especially high despite the fact that the shafts may be running at high speed (absolute). This reduces the machining precision required for these bearings and hence the cost.

The variable annulus shaft 16 requires a mechanism allowing axial shifting of the annulus 19 making traction contact with the planet cone 7 in order to change the speed ratio between the prime mover and the vehicle. The variable sun shaft 11 also requires a mechanism to axially shift the variable sun disc 20 in order to change the speed of the flywheel relative to the prime mover/vehicle. These two variable branches may utilise methods employed in the Turbo Trac variator (patent nos. US6001042 & US7856902) to facilitate this ratio control.

The bevel gears 2,3,5,6 may be spiral bevel gears to reduce noise and vibration and provide smooth torque transfer and increased fatigue life for the gear teeth and surfaces. Klingelnberg spiral bevel gears (where the teeth are not tapered) in particular may be used which can be generated with a hobbing process much like automotive gearboxes and hence benefit from low cost in volume production despite their seemingly complex geometry. Palloid tooth form may also be produced by hobbing but has greater bending strength since the teeth are tapered.

All of the bevel gears mentioned (2,3,5,6) may also be replaced by traction-drive surfaces or friction drive surfaces (sometimes referred to as friction gears). Such arrangements are described in more detail below.

Fig. 3 is a schematic representation of a first transmission arrangement that employs a variator as described above. The variable annulus shaft 16 is hollow, allowing the constant sun shaft 1 to pass through coaxially on the same side of the MCVP 28, being connected to the prime mover 29 via a gearbox 30 and a clutch 31. This arrangement conveniently allows the differential 32 to be placed in the middle of the vehicle's powered axle, between the prime mover 29 and the MCVP 28, since this is permitted by the relative sizing of the prime mover, MCVP and a flywheel 33. The prime mover 29, gearbox 30 and clutch 31 may be a standard automotive or motorbike engine and gearbox arrangement 34 with the included clutch 31. The flywheel 33 is connected to the variable sun shaft 11 via a clutch 35 and a gear box 36; order of said clutch and gearbox in the torque path is chosen for ease of component design/selection. The gearbox 36 may be a single fixed ratio, or a plurality of selectable ratios in order to behave as a ratio range extender for the flywheel branch of the MCVP, which arrangement will be immediately apparent to those of ordinary skill in the art. The range extender may have capability to change gear without torque interruption (such as, but not limited to, dual- or multiple-clutch gearboxes) so as to allow continuous charging and discharging of the flywheel over a large range of vehicle/prime mover speeds.

In the layout proposed in Figure 3, all shafts are parallel to the axle of the vehicle (they run transverse/across the vehicle). If the flywheel gearbox 36 does not reverse the rotational direction relative to the variable sun shaft 11, the flywheel 33 rotates in the same plane as the wheels 37 but in the opposite direction. This causes the reaction to the flywheel gyroscopic moments acting on the vehicle during cornering to counteract vehicle roll which adds stability to the vehicle and also reduces the net loss of tyre traction due to lateral load transfer. This feature is of particular benefit to racing applications, but also to road cars. If the flywheel gearbox does reverse the direction of rotation, then this can be counteracted by first ensuring the flywheel is in the correct orientation to rotate oppositely to the wheels, then selecting a gearing arrangement that will ensure the correct direction of shaft rotation at the vehicle wheels, whilst ensuring the drive from the prime mover is also in the correct rotational direction.

Mechanical brakes 38 can bring the vehicle safely to rest in event of failure of any control critical components in the transmission. The flywheel and prime mover clutches 35, 31 are simply disengaged in order to stop supply of power to the vehicle.

2. Modified MCVP hybrid transmission (CVT/IVT)

The functionality and intents of the arrangement depicted in Fig. 4 are identical to those of the first embodiment. Here, however, there is no constant sun branch and the prime mover is instead connected to the carrier branch. This does not change the functionality, since there is a constant speed ratio between the constant sun branch and the carrier in the variator. This arrangement potentially reduces the cost of the transmission, since an entire set of bevel gears (or traction surfaces) on the planet can be eliminated.

3. Torque-controlled MCVP hybrid transmission

It will be apparent from the foregoing that the MCVP described above is a dual ratio-controlled planetary variator that can also operate in a (quasi-)torque-controlled mode. This mode is achieved by virtue of its similarities with the conventional planetary gear set (comprising a sun gear and shaft, an annulus internal gear and shaft, both of said gears mesh with a set of planet gears located in the planet gear carrier connected to a carrier shaft), which is known to be used as a torque-splitting device in transmissions. When all of the three branches are free to rotate, it is a mechanism with "two degrees of freedom"; two of the shaft speeds must be known to determine the third shaft speed. There is a linear relationship between all three speeds that is a function of the planetary ratio. In contrast, the torque at all branches is known if the torque at any single branch is known, and these are again related by the planetary ratio. Additionally, it is well known that the sign of torque on the carrier branch is opposite to that on the other two branches (sun and annulus/ring).

In this arrangement three branches of the MCVP are used: the carrier, one of the annuli/rings and one of the suns. These three branches make up a conventional planetary arrangement, but here the planetary (or epicyclic) ratio is continuously variable. The flywheel, the prime mover and the vehicle final drive are each connected to a different branch. Clutches may be used to vary which of the branches the prime mover, flywheel and vehicle are connected to, depending on the mode of operation.

Actuation of one (or both) of the ratio control mechanisms can change the planetary ratio and thus adjust the torque split. Each branch will accelerate depending on the torque applied to it (whilst obeying the linear speed relationship), thus facilitating torque control. The transmission system is controlled by controlling the engine torque in conjunction with the planetary ratio, in response to driver inputs or road conditions. In this mode, the vehicle speed depends on both the engine and flywheel speeds.

In this arrangement, any planetary variator may be employed to form this torque-controlled transmission (including but not limited to the NuVinci CVP, the Kopp variator and the Milner CVT). An advantage of using the MCVP described herein - as compared to the other variators listed above - is that a given planetary ratio can be achieved in a variety of actuator positions (if both ratio control mechanisms are changed simultaneously).

4. Traction vs. friction drive; Control mechanisms for variable ratio branches

As mentioned above, the MCVP described herein may be a traction drive, where a thin film of traction fluid is sheared between the contacts. However, due to low contact spin in the device, it may also be used a friction drive (i.e. dry running metal-metal contact).

TurboTrac patents US6001042 and US7856902 each describe mechanisms for controlling variator ratios and methods for providing the necessary normal contact forces for traction/friction drives.

5. MCVP geometrical choices

In the arrangements described above, any of the constant ratio sun and annulus branches 2,6 can comprise bevel gears or bevel traction surfaces.

As is well known to one skilled in the art, the geometry of mating bevel gears is always chosen such that there is no difference in linear velocity between the gear surfaces at any axial position in the mesh (see classic reference text, Shigley's "Mechanical Engineering Design", section on bevel gears).

The required geometry is depicted schematically in Fig. 5 for an external mesh (two convex bodies 2,3 – corresponding to a constant ratio sun branch 2 for an MCVP) and in Fig. 6 for an internal mesh (one concave body 6 and one convex body 5 – corresponding to a constant ratio annulus branch 6 for an MCVP). This is achieved by selecting appropriate cone angles 52,56 such that a line 54 through the gear mesh (defined by the intersection of the contact tangent plane and a radial plane defined by the two axes 51,53) and the two respective rotational axes 51,53 all intersect at a the same point 55.

If equivalent geometry is used for traction or friction surfaces, the absence of spin (differential velocity) in the contact results in very high contact efficiency and maximised traction coefficient. Further benefits of using traction surfaces in place of meshing bevel gears are that the transmission will be almost silent (no gear whine), there is potential for simpler and cheaper manufacture, and the pitch line velocity can be very much higher than that tolerated by gears (allowing a smaller transmission to be used, running at higher speed for the same power capacity).

Furthermore, with traction surfaces, the designer has much more freedom to select a desired transmission ratio, since the effective gear module of a traction surface is infinitesimally small, allowing any value of pitch diameter to be selected.

Furthermore, since there is no differential velocity (spin) present in such gear meshes or traction meshes, any axial thickness (face width) can be selected to obtain a desired contact fatigue life. A crown radius may also be provided on each surface if a traction contact is employed.

The speed ratio between a constant ratio branch of an MCVP and an MCVP planet (assuming the rotational axes themselves remain fixed in space) is purely a function of the MCVP actuation cone angle 52 and the bevel angle 56 on one of the bevel gears/traction surfaces. Consequently, placing the gears or traction surfaces at any axial position results in the same gear ratios for the MCVP device, affording flexibility to the design of a particular MCVP.

In one embodiment, the bevel gears/traction surfaces 3, 5 on the planet may be different features. In another embodiment, the bevel gears/traction surfaces 3, 5 on the planet may be the same feature, meaning that they will have the same bevel angle 56.

6. <u>Various arrangements with IVT functionality</u>

An MCVP 28 can be configured in numerous ways to provide an infinitely variable transmission (IVT) without needing to couple to a conventional planetary gear set. In general this is achieved by rotating the planet carrier 9, and using two annulus branches (or alternatively two sun branches), at least one of which is a variable ratio branch, grounding one annulus (or sun) branch, with the speed of the other annulus (or sun) branch found by summing the linear velocities of the planet and the carrier at the point of contact; if suitable geometry is chosen, at one point along the actuation cone 58 these two linear velocities will sum to zero. A beneficial feature of this kind of IVT is that no recirculating power exists. A further beneficial feature of the MCVP device is that the axial position of the variable ratio branch at which the geared neutral condition is reached can be freely selected; allowing free control of how the ratio spread is shared between forwards and reverse.

This is depicted for one arrangement of an infinitely variable MCVP in Fig. 7, where a constant ratio annulus branch 6 and a variable ratio annulus branch 19 are employed to provide the IVT functionality. The planet axis 51 rotates about the main axis 53, meaning the planets orbit within the device, and either one of the annulus branches

6,19 is irrotational (fixed to ground) and the other is used as a transmission output.

When the contact point 57 on the actuation cone 58 lies on the line 54 corresponding to the bevel angle 56, the geared neutral condition is reached (i.e. the transmission output has zero angular velocity), with forwards and reverse achieved either side of this point. This effect is also depicted in Fig. 8, where instead a constant ratio sun branch 2 and a variable ratio sun branch 20 are similarly employed to provide IVT functionality.

If the line 54 corresponding to the bevel angle 56 lies outside the limits of the actuation cone 58, then no geared neutral condition is provided (i.e. this is not an IVT configuration, but rather a CVT configuration).

The MCVP carrier 9 must rotate to provide an IVT without additional gearing. The input to the transmission may be, for example, the carrier 9 or any opposing branch to the grounded branch (a sun and an annulus are opposing branches to each other). Some possible combinations of grounded branch and IVT output branch (possessing geared neutral) are shown in the table below:

Branch fixed to ground (not rotating)	Output branch
Constant ratio annulus 6	Variable ratio annulus 19
Variable ratio annulus 19	Constant ratio annulus 6
First variable ratio annulus 19	Second variable ratio annulus 19
Constant ratio sun 2	Variable ratio sun 20
Variable ratio sun 20	Constant ratio sun 2
First variable ratio sun 20	Second variable ratio sun 20

In one envisaged implementation, these combinations may be used to construct an MCVP that functions as a standalone launch device for a vehicle, providing an efficient IVT without power recirculation.

6. <u>Geometrical permutations</u>

The cones 58 of the MCVP may face in opposite directions or in the same direction (generating either two variable suns or two variable annuli). Various different configurations are shown in Figs. 9 to 12.

As will be appreciated by persons of ordinary skill in the art, smaller cone angles 52 provide for lower spin and an axially longer device, whereas larger cone angles 52provide for higher spin, and an axially shorter device.

It will be appreciated that whilst various aspects and embodiments of the present invention have heretofore been described, the scope of the present invention is not limited to the particular arrangements set out herein and instead extends to encompass all arrangements, and modifications and alterations thereto, which fall within the spirit or scope of the invention.

It should also be noted that whilst particular combinations of features have been set out herein, the scope of the present invention is not limited to those particular combinations, but instead extends to encompass any combination of features disclosed in this application, in any of the applications from which this application claims priority and/or the accompanying supplement; and to encompass any of these features in isolation.

TRANSMISSION SYSTEM

Field

This invention relates to transmission systems, particularly but not exclusively to transmission systems for vehicles. Another aspect of the invention relates to a variator for such a transmission system.

Particular reference is made hereafter to the use of such systems in a road vehicle, but it will be appreciated by persons of ordinary skill in the art that the system disclosed herein has many other applications, and as a consequence the following description should not be read as being a limitation of the scope of the present invention.

Background

Many conventional road vehicles have internal combustion engines that are large and powerful enough to maintain a cruising speed on a motorway, for example, that is much higher than is permitted by the speed limits in the United Kingdom, and such engines are in this respect at least much more powerful than is strictly necessary. This effectively surplus power capability tends to be provided by manufacturers so that the vehicle is better able to accelerate by having sufficient power (after overcoming resistance forces) to change the kinetic energy of the vehicle. However, such larger engines tend to consume a relatively large amount of fuel (compared, for example, to smaller more frugal engines) and since fuel is both expensive and environmentally damaging (both in terms of its extraction and its combustion) it would be beneficial for the capacity of such engines to be reduced.

A further concern is that the amount and nature of engine emissions tend to vary considerably over the range of operating conditions experienced by the engine. Larger trucks, buses, lorries and off-highway vehicles tend to have larger diesel engines that typically produce peak emissions when under transient operating conditions, and as a consequence the performance of new engines of this type tends to be compromised in the design stage in order to meet increasingly stringent emissions regulations.

One proposal for tackling this issue of engine transience is to use a so-called "series" hybrid powertrain in which an electric transmission is used. In this proposed arrangement, the engine runs efficiently in a more or less constant condition and is used to power a generator that delivers electrical power to motor-generators at the wheels/final drive of the vehicle – which wheels/final drive can also accomplish regenerative braking. Braking energy and any surplus engine power generated while the vehicle is moving is sent to a storage device, such as an electrochemical battery, and the engine can also be switched off when the vehicle is temporarily stationary (for example, at traffic lights) - responsive vehicle behaviour when pulling away from standstill being provided by the motor-generators.

Whilst series hybrids of the type described above generally do not add power capability, they can improve efficiency (under the right conditions). However, series hybrids tend to be expensive to produce due to the significant added cost of the electric motors and batteries, and the additional weight that such devices add to a typical vehicle also impacts upon performance and efficiency. The batteries themselves are also an environmental concern and are costly even in mass production, due to the materials and processes required in manufacture. Another important drawback of such systems is that power flow through the powertrain requires multiple energy conversions (between chemical, potential, mechanical, kinetic and electrical forms) and resultant energy losses.

An alternative proposal is the so-called "parallel hybrid" in whcih two means are provided for propelling a vehicle. Such an arrangement offers an increase in power capability (by providing two means of propelling the vehicle), and those means can be used independently or in combination to offer more efficient operating conditions for the engine. However, electric parallel hybrids still add significantly to the cost of the vehicle, and still exhibit the deficiencies outlined above for series hybrid powertrains.

A further proposal is the so-called mechanical hybrid, such as those incorporating lightweight high-speed flywheels (such as those by Flybrid Systems, see www.flybrid.co.uk). The Flybrid systems are effectively "bolt on" devices that provide for kinetic energy recovery (regenerative braking), and are designed to interface with conventional powertrain architecture that comprises a clutch, a discrete gearbox and a differential. The hybrid component of the Flybrid system comprises a flywheel, a fixed gear stage, a clutch and a continuously variable transmission (CVT).

Flybrid Systems have also demonstrated a so-called clutched flywheel transmission (CFT) that comprises two sets of three constantly meshed gears and a clutch per pair of gears (one designated from each set), and which uses controlled clutch slip to move between the fixed ratios. This CFT system behaves in a similar way to the aforementioned CVT system but is less expensive to produce and more suitable for low power applications.

Both of the aforementioned systems are so-called "parallel hybrid" systems that are capable of propelling the vehicle by means of a prime mover (such as an internal combustion engine) or the flywheel or a combination of both. The aforementioned systems also have "full hybrid" capability in that they can accept a proportion of surplus engine torque during ordinary driving, thereby enabling the engine to operate in a more efficient regime than in conventional powertrains over a range of conditions.

However, whilst the systems proposed by Flybrid offer advantages over previously proposed systems, they still do not allow the engine to operate fully independently from the instantaneous requirements of a vehicle, principally because the engine is accelerated through discrete gears in a gearbox. If a system were to be devised that enabled the engine to be fully isolated from the vehicle, then the efficiency of the engine could further be improved.

The present invention has been devised with the foregoing problems in mind.

Summary

In accordance with a presently preferred embodiment of the present invention, there is provided a variator (otherwise referred to as an MCVP) comprising a first and a second cone, said cones being rotatable about a common axis that is inclined relative to a main axis so that said first and second cones each provide a side that is substantially parallel to said main axis.

Protection is also claimed for a cone substantially as herein described, an MCVP as herein described, a vehicle transmission, and a vehicle incorporating an MCVP.

Particular note should be taken of the fact that the scope of the present invention includes any combination of features herein described.

Brief Description of Drawings

Illustrative embodiments of the present invention are described hereafter by way of illustrative example with reference to the accompanying drawings, in which:

Fig. 1 is a schematic representation of two truncated cones arranged along a common axis in a first configuration;

Fig. 2 is a schematic representation of alternative cone configurations;

Fig. 3 is another schematic representation of another cone configuration;

Fig. 4 is a schematic planetary analogy of an illustrative variator;

Fig. 5 is a schematic representation of an illustrative vehicle transmission;

Fig. 6 is a schematic representation of an arrangement that is functionally equivalent to the arrangement depicted in Fig. 5; and

Figs. 7(a) to 7(h) are schematic representations of several possible power paths.

Fig. 8 is a schematic representation of an illustrative variator configuration;

Fig. 9 is a cut-away schematic representation of the variator depicted in Fig. 8;

and

Fig. 10 is a diagrammatic representation of a transmission system that incorporates the variator depicted in Figs. 8 or 9; and

Fig. 11 is a rendered image of the variator depicted in Figs. 8 and 9 in use with a prime mover and a flywheel.

Detailed Description

As will later be described in detail, the system described herein offers all the capabilities of previously proposed mechanical flywheel hybrid systems, whilst also offering further significant functional benefits thereover.

For example, rather than being a bolt-on system (such as that proposed by Flybrid), the system disclosed herein entirely replaces a conventional stepped (discrete gearbox) transmission. The system disclosed herein embodies the benefits of both series and parallel hybrid powertrains, in particular: increased power capability beyond that of the prime mover alone (parallel hybrid), and permitting the engine to operate entirely independently of the instantaneous vehicle requirements and thus achieve greater efficiency (series hybrid).

In a preferred arrangement, the transmission system disclosed herein is used in conjunction with a prime mover (for example an internal combustion (IC) engine) and a flywheel. As will be described in more detail below, the flywheel can be used to supply kinetic energy whilst also simultaneously accepting power from the prime.

The flywheel thus acts as a buffer by being able to accept surplus engine power (even during regenerative braking) and by being able to supply extra power to the vehicle when needed, thus aiding engine downsizing.

The system disclosed provides numerous additional useful modes of operation that are beneficial in a wide variety of ground vehicle applications. For example, the system provides infinitely variable transmission (IVT) functionality (with reverse gear) for the final drive, with the flywheel being able to be charged with the prime mover power even whilst the wheels are in a powered neutral mode (where this energy is normally wasted as heat in power recirculation). It is also possible to start the engine with the flywheel if desired. Furthermore, a variety of control strategies are also possible, which can be optimised for energy efficiency.

All this is potentially achieved at a much lower cost to current electric alternatives. This is largely due to keeping energy in the mechanical kinetic domain using flywheels, which also addresses the aforementioned issues associated with energy conversion losses. A vehicle with an electric transmission must have “X” kilowatts' worth of electrical machines (e.g. motor-generators) to deliver "X" kilowatts of power at the wheels, whereas a mechanical system using flywheels (such as the arrangement disclosed herein) can deliver more power than the prime mover (which could still be an electric machine) since more power effectively means more torque in the mechanical components, which just need to be designed to be able to withstand the increased loads. Mechanical systems reduce in cost in mass production and allow widely available and fully recyclable materials to be used, and are thus potentially a more sustainable and environmentally friendly solution than using expensive, heavy and less environmentally friendly electrochemical batteries.

The advantages outlined above derive from the use of a novel continuously variable transmission (CVT) that has up to five usable inputs/outputs ("branches") with two independent ratio control mechanisms, each of which is operable to change the speed ratio of one particular branch relative to all the others.

Whilst the majority of previously proposed CVTs tend to have just one input and one output ("branches"), two other CVTs (the so-called Milner CVT and the NuVinci CVP (continuously variable planetary)) have previously been proposed that have more than two branches. The developers of these systems have acknowledged the potential for use of their CVTs in hybrid vehicles, where more than one means of propelling the vehicle needs to be matched to the vehicle requirements. Both also share some similarity with a planetary gear set and so have power-split capabilities. However, both these multiple-input CVTs have only one ratio control mechanism, which upon actuation alters the speed ratios between all branches (i.e. any pair of branches), which imposes limitations on functionality. The ability to actuate two distinct mechanisms as provided in the system disclosed herein is equivalent to having two independent CVTs within one component, allowing the ability to independently choose an appropriate speed ratio for two different means of propelling a vehicle. This is useful in a multitude of applications, but is especially important for flywheel hybrids. The speed of the flywheel inherently changes during energy transfer (control of the flywheel speed controls the energy storage and recovery), since for a given flywheel inertia, the energy stored is purely a function of rotational speed; thus independent control of flywheel speed from the engine and the wheels is important.

The novel CVT described herein (one illustrative planetary analogy of which is shown schematically in Fig. 4 below) may be referred to as a Multi- Continuously Variable Planetary (or MCVP) due to its similarities to a planetary gear set and the aforementioned NuVinci CVP. The MCVP differs, however, from the NuVinci CVP by having more than one actuation mechanism. Providing more than one actuation mechanism is equivalent to having two CVTs but since all the branches contact the same set of idling planet elements, all possible power paths cross only a maximum of two traction contacts (effectively a single CVT). Therefore, assuming efficient elasto-hydrodynamic conditions are generated at each of these contacts, the MCVP disclosed herein provides significantly higher transmission efficiencies than two CVTs in which some power paths involve crossing two CVTs (equating to 4 traction contacts in series).

In general, traction contacts in parallel add linearly to the torque capacity of a CVT, but traction contacts in series reduce efficiency with a multiplicative relationship. The MCVP benefits from both of these facts. There is also the benefit of reduced mass and component count (and hence cost) owing to the same components contributing to both CVT mechanisms.

As aforementioned, the transmissions disclosed herein are not limited to use in vehicles. Furthermore, the transmissions disclosed herein are not limited to vehicles or machinery where the primary source of power is an internal combustion engine. Indeed, most motor devices (whether combustion engines, electric machines, hydraulic motors etc) have regimes of operation where they are most efficient, and benefit from the properties gained from using the system disclosed herein. Thus the term "prime mover" is used here to not restrict the invention to IC engines, since the system is equally suited to any motor device.

The MCVP disclosed herein comprises a novel planetary traction drive (depicted schematically in Fig. 1 below) that employs planets which are double truncated cones inclined at an angle to the main shaft axis that is equal to half of the cone angle, thereby producing two effective straight edges aligned parallel to the main axis. Two independent actuator mechanisms control the axial position of a disc and a ring (green contact patches) that make contact with the inner and outer effective edges of the planet, which changes the contact radius on the planet and thus the linear speed, thereby changing the rotational speed of the said disc and ring. The ring and the disc rotate about the main rotational axis. Thus there are two independently controllable ratio mechanisms. One other "disc" and one other "ring" (red contact patches) also make contact and provide a means of clamping the planet on all sides and a means for supplying pressure (for example, hydraulic/sprung etc) to induce elasto-hyrdrodynamic conditions in the contact fluid for efficient torque transfer. The planets themselves are mounted via bearings seated on the cylindrical parts of the truncated cones into a carrier which can also rotate about the main axis. The red contact points which are constrained from moving axially can be replaced with toothed gears (depicted schematically in Fig. 3 below) in between the two cones in order to increase mechanical efficiency (although

SUPPLEMENT

bevel teeth are required) at the expense of compactness.

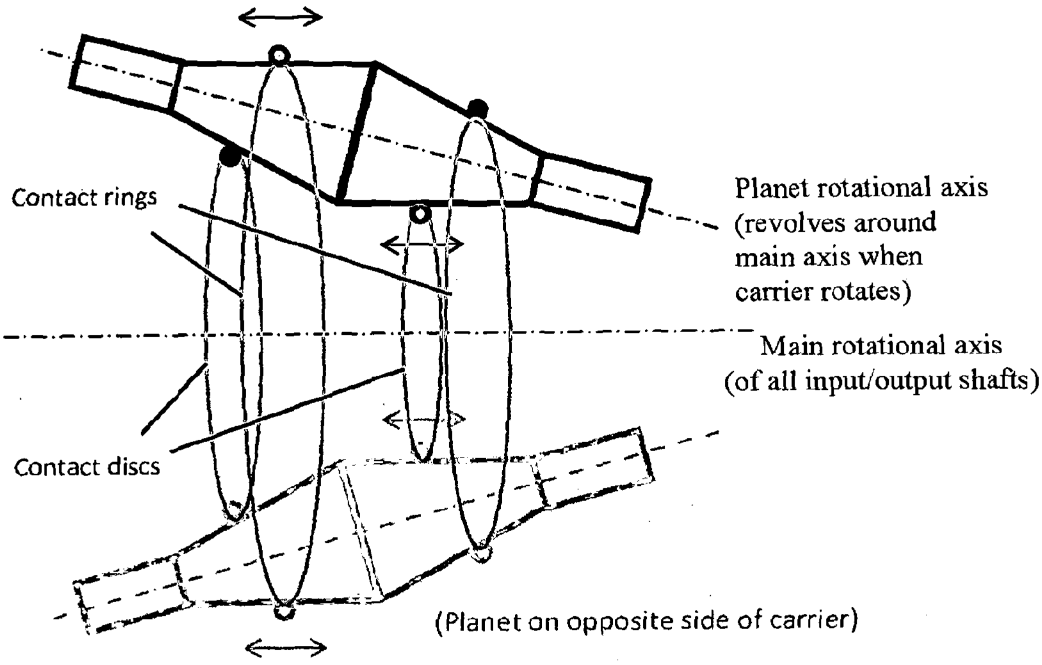


Fig. 1

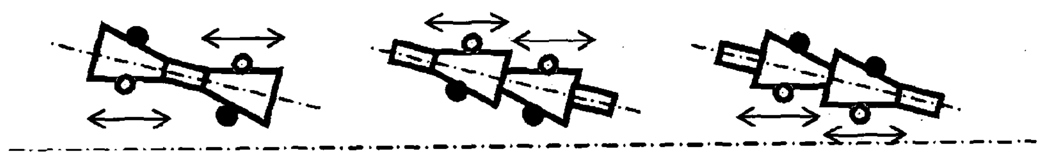


Fig. 2

Although the cones are shown in Fig. 1 as facing away from one another, in alternative arrangements (depicted schematically in Fig. 2) they may also face towards one another (or in the same direction, although this is less preferred as it will cause the bearings to react higher loads).

SUPPLEMENT

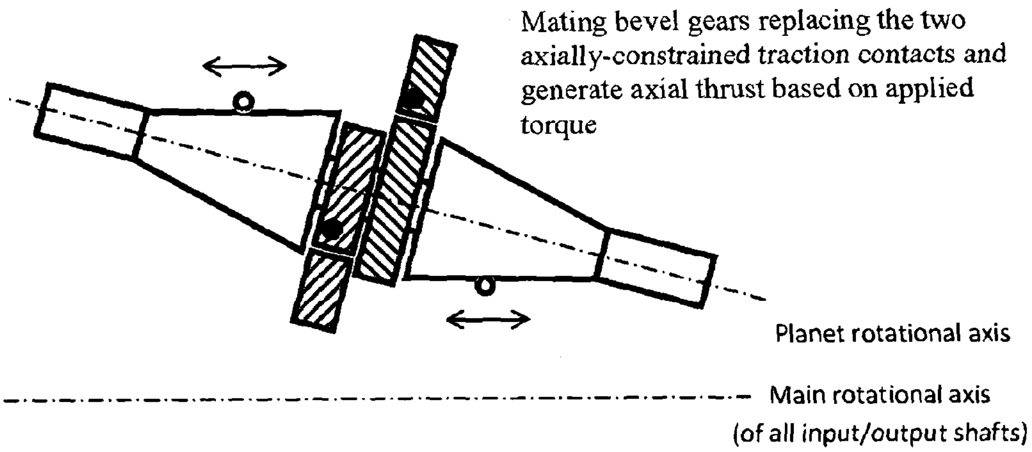


Fig. 3

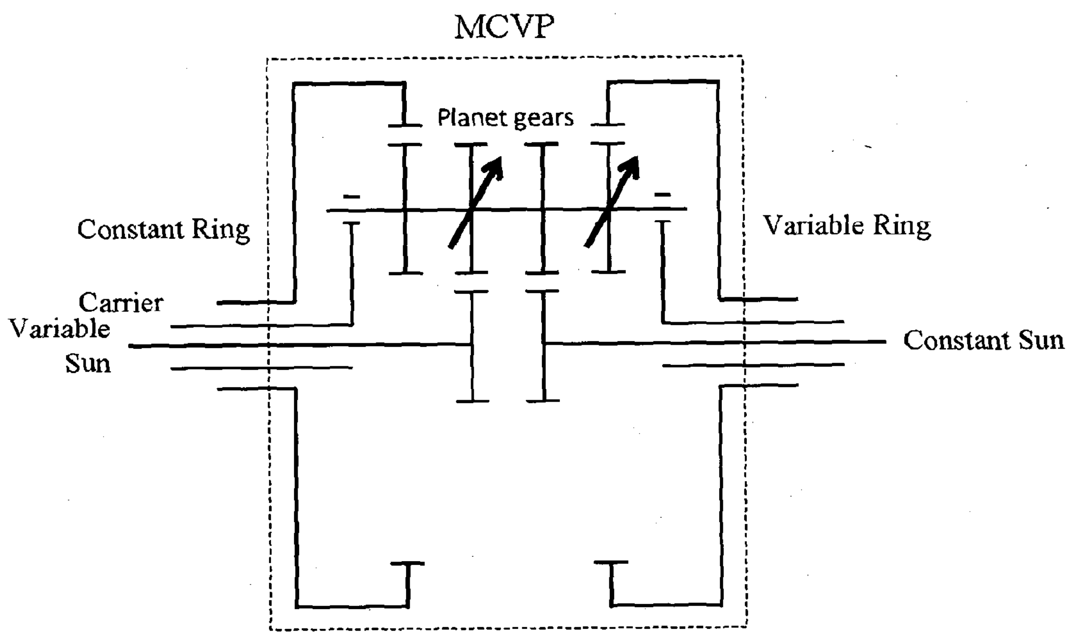


Fig. 4

In accordance with convention, only one set of conical rotors are shown in the figures above, but it will be appreciated by persons of ordinary skill in the art that in reality a plurality of conical rotor pairs will be symmetrically arranged around the main axis.

The abovedescribed MCVP may be employed in a vehicle transmission that couples two at least two sources of motive power to one or more driven elements (such as a pair of wheels on an axle). Fig. 5 below is a schematic representation of one such arrangement in which the abovedescribed MCVP is coupled between first and second sources of motive power (in this illustrative example, a flywheel (labelled "FW"); a prime mover (labelled "PM") such as, inter alia, a combustion engine, an electric machine or a hydraulic machine)), and a differential (labelled "Diff") that is coupled to a pair of driven wheels on a braked axle.

As shown in Fig. 5 below, in this embodiment the flywheel is connected to the variable "sun" branch of the MCVP, the prime mover is connected to the constant "sun" branch, the final drive is connected to the variable "ring" branch and the constant ring branch is fixed to ground (no rotation). The carrier is necessarily free to rotate. The flywheel and the prime mover are connected to their respective branches by means of a clutch (as shown) and a fixed ratio gear stage (not shown) may also be provided before or after the clutch in order to be at the right speed in the transmission.

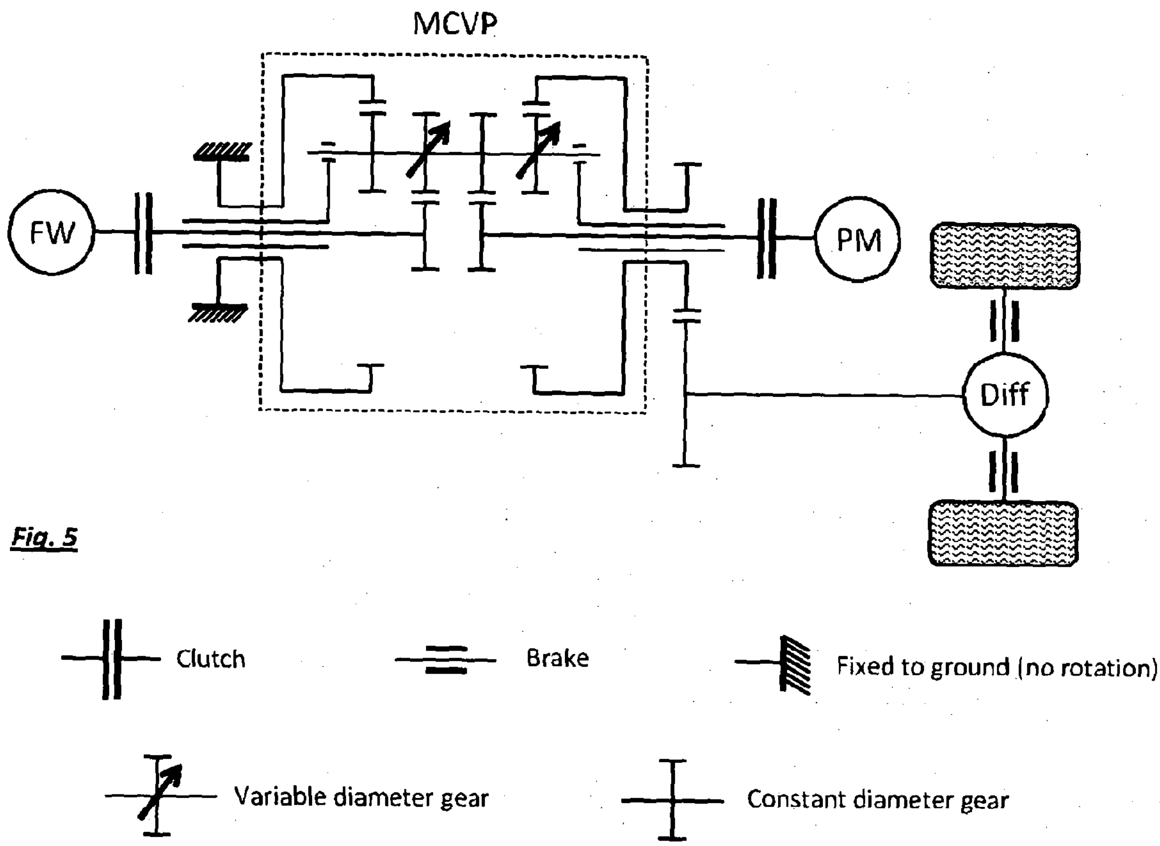


Fig. 5

As will be appreciated by persons of ordinary skill in the art, the prime mover can be switched on and the prime mover clutch can be engaged and fully closed which causes the constant sun branch to rotate and also defines the speed of the carrier branch, since the constant ring branch is fixed to ground. There is a constant speed ratio between the prime mover and the carrier branch.

When the diameter of the variable planet gear in contact/mesh with the variable speed output ring is the same as the diameter of the constant planet gear in contact/mesh with the grounded ring, the final drive is in a powered neutral condition. The prime mover is rotating and supplying power, but the final drive is locked stationary. Thus this device is capable of operating as an IVT (Infinitely Variable Transmission).

In common with all IVTs, in a powered neutral mode, any external torque exerted at the vehicle wheels will not cause the vehicle to move, such as in the case of being stationary on an inclined surface. Additionally, this means there is no need for a pulling-away clutch, reducing the number of components required. The final drive direction of rotation reverses either side of the powered neutral condition, providing the means for a reverse gear. The ratio spread either side of powered neutral can be adjusted to favour forward motion if desired by changing the diameter of the constant ring and planet gears.

A key function offered in this mode is that other branches of the system remain rotational, and actuation of the other ratio control mechanism provides continued functionality for that respective branch independent of the powered neutral condition of the final drive. This allows the flywheel to be charged with the engine power by actuating the other ratio mechanism so as to increase the flywheel speed.

In the powered neutral mode of conventional IVT systems, the power is just recirculated and ultimately dissipated (wasted) as heat in the transmission. An advantage of the arrangement described herein is that in this instance the power that would otherwise be wasted in a conventional IVT may be stored for later use, thus increasing system efficiency. As the vehicle pulls away, the torque subtracted from the transmission by increasing the flywheel speed is controllably reduced.

Since the prime mover may well be producing sufficient power (if operating in a constant condition) to cause the wheels to slip at low speed, the flywheel can conveniently continue to subtract torque to prevent this from happening (traction control system increases flywheel torque if wheels begin to slip).

In order to accomplish kinetic energy recovery, both variator mechanisms require actuation, in order to slow down the final drive and simultaneously speed up the flywheel.

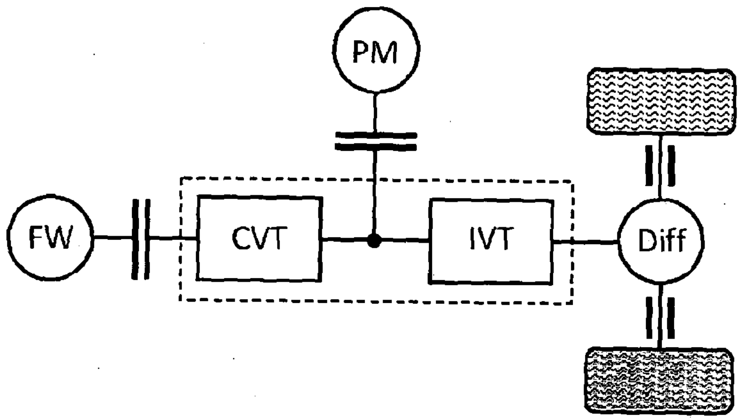


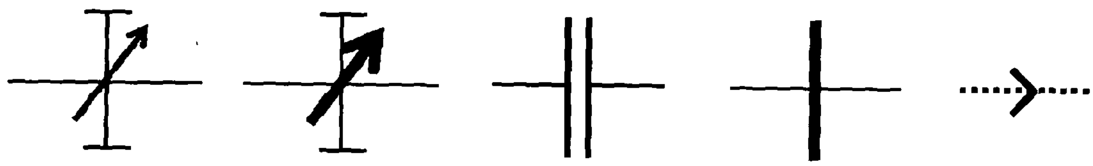
Fig. 6

The arrangement shown schematically in Fig. 6 is functionally equivalent to the arrangement depicted in Fig. 5, and from this it is perhaps easier to visualise how simultaneous regenerative braking and engine charging of the flywheel is possible.

It has previously been proposed that changing the ratio of a CVT will apply a torque to two inertias connected either side of the CVT and cause one to speed up and one to slow down (this is how kinetic energy recovery is achieved with flywheels). Simultaneous kinetic energy recovery (regenerative braking) and engine charging of the flywheel is accomplished by changing the IVT ratio to apply a negative torque at the wheels whilst changing the CVT ratio such that the flywheel speeds up; the positive torque exerted on the transmission side of the CVT by changing the flywheel speed must equal the sum of the torque supplied by the engine and the positive torque on the transmission side of the IVT. This cannot be achieved as easily and efficiently with the aforementioned previously proposed flywheel systems that bolt-on to conventional stepped transmissions, which would require slipping of the engine clutch and thus not be very efficient.

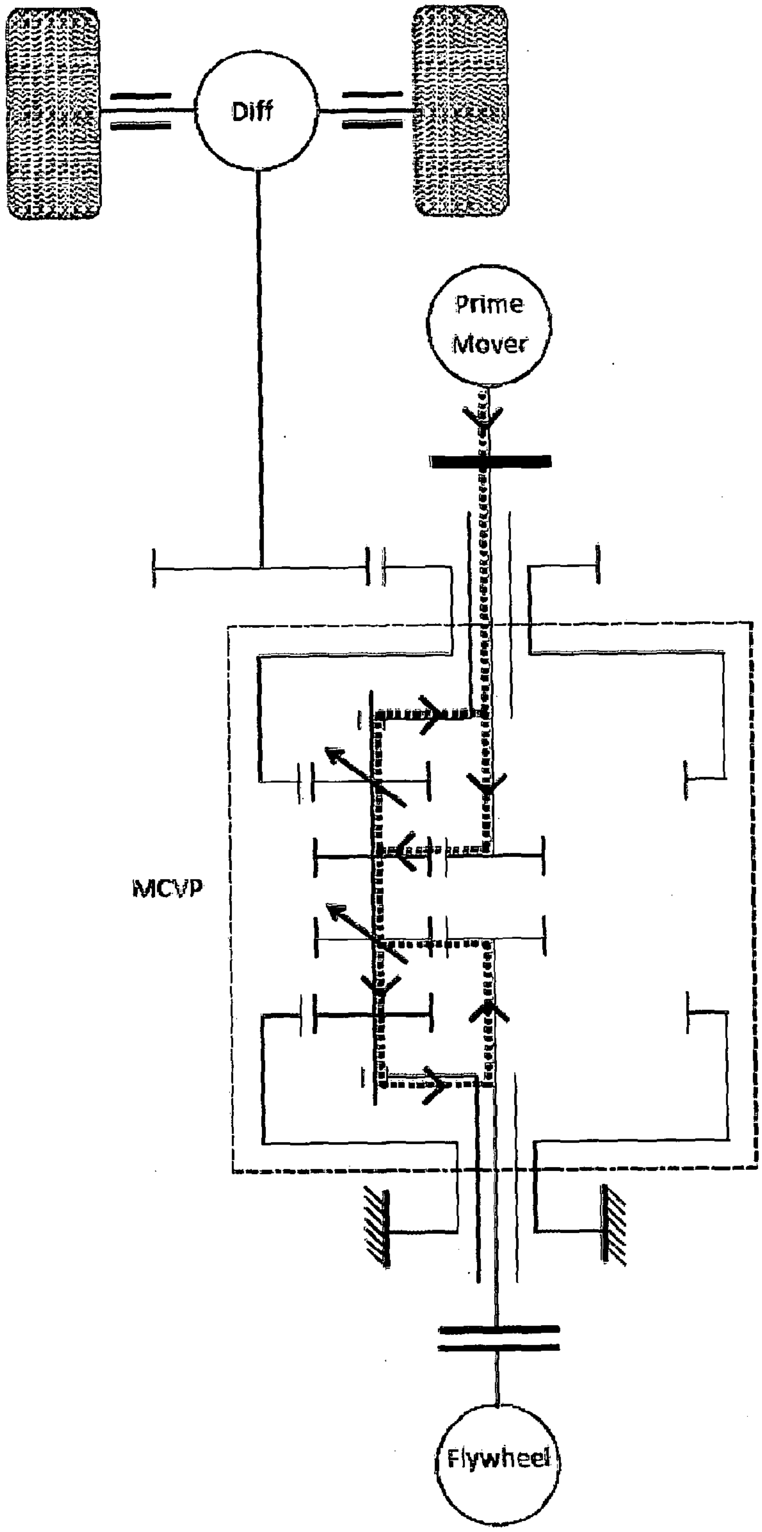
Fig. 6 also shows two variators (the CVT and IVT) in the box that represents the MCVP in preferred configuration. If, instead of the aforementioned MCVP, two separate CVTs were used, a regenerative braking path would have to cross two CVTs per one way trip, and as such "round trip" power would have to cross four CVTs – an arrangement that is not particularly efficient. The arrangement described herein only effectively crosses one CVT per one-way trip (hence only two per round trip) and as a consequence is more efficient.

As has briefly been explained above, the MVCP disclosed in the application has several operating modes, and schematic representations of the respective power paths for each of these modes are shown in Figs. 7(a) to 7(h), in which the following symbols have the following meaning:



Variable radius gear not being actuated	Variable radius gear in possible actuation	Open clutch	Closed clutch	Power flow

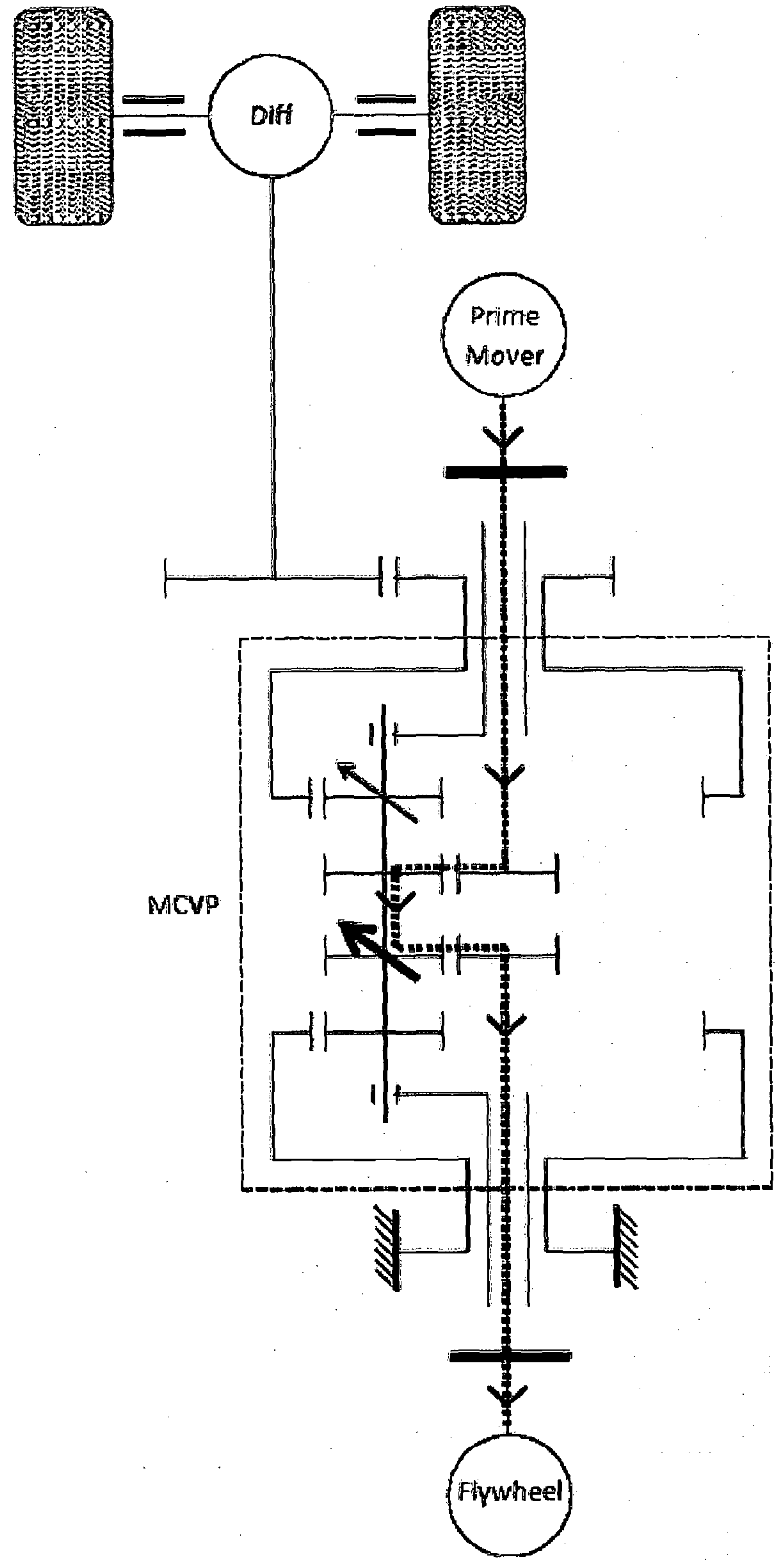
SUPPLEMENT



Ordinary powered-neutral mode (power recirculated & dissipated as heat)

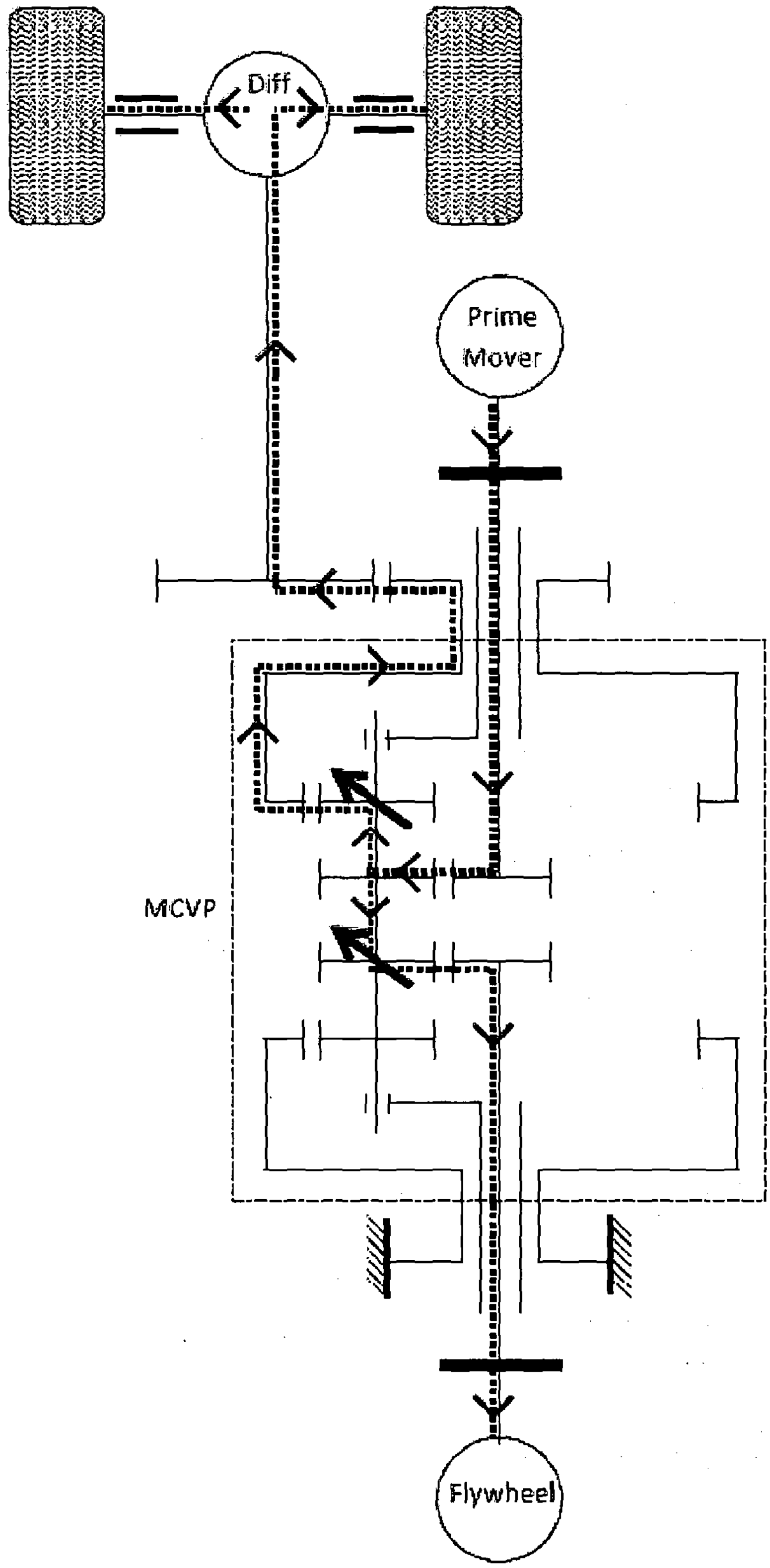
Fig. 7(a)

SUPPLEMENT



Charging of flywheel in powered-neutral mode

Fig. 7(b)



Surplus prime mover power (incl. traction-limited acceleration)

Fig. 7(c)

SUPPLEMENT

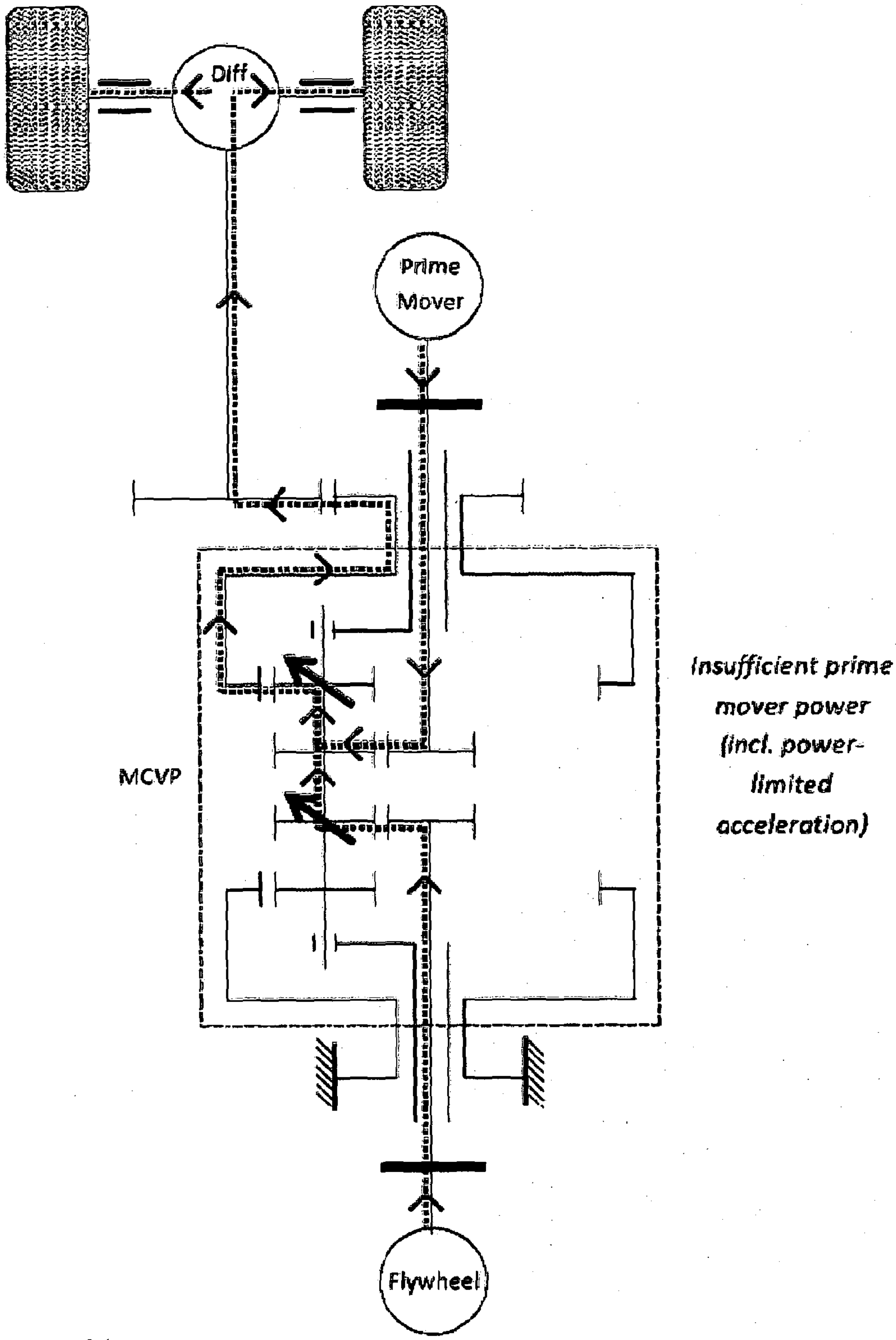


Fig. 7(d)

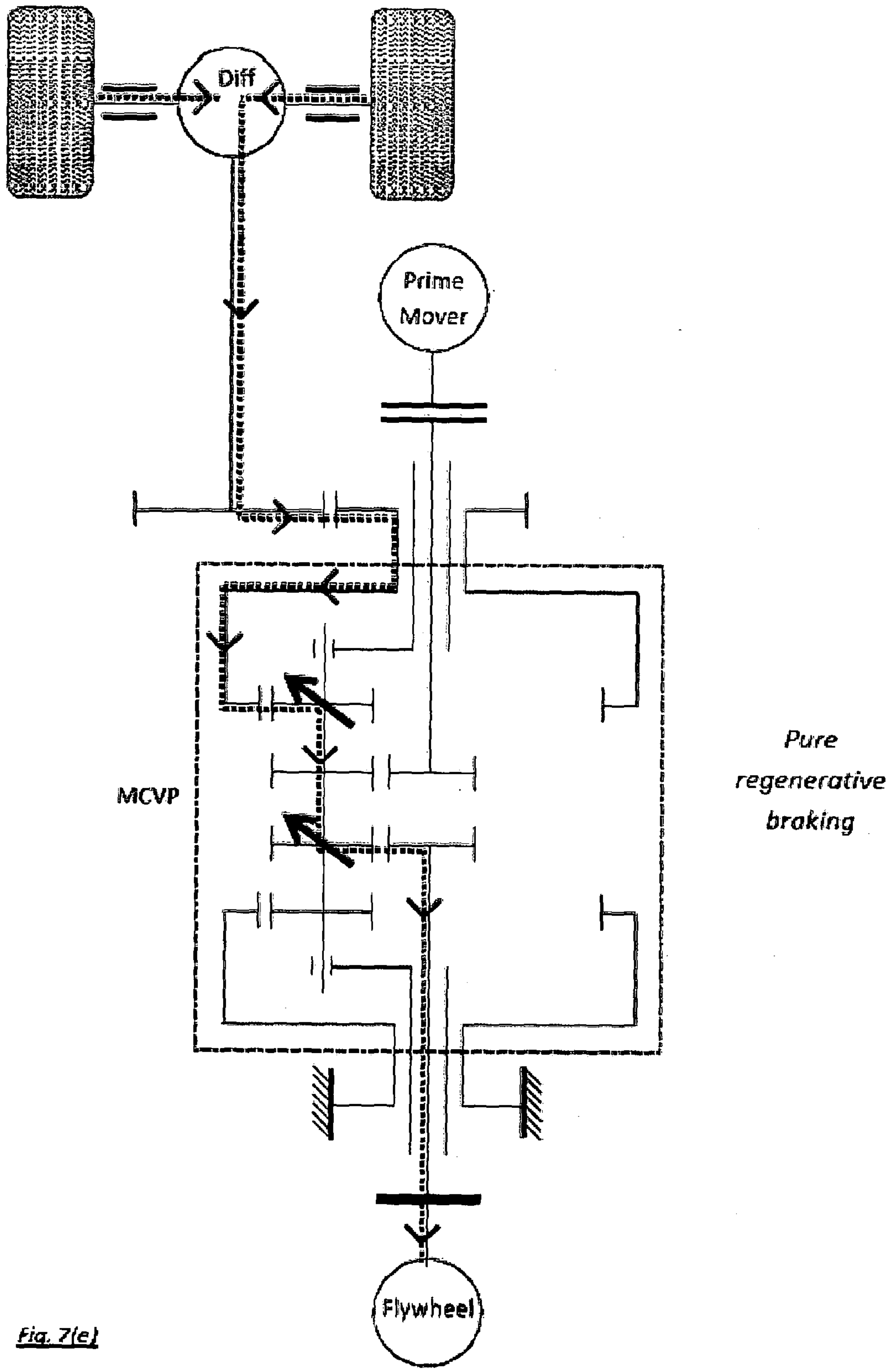
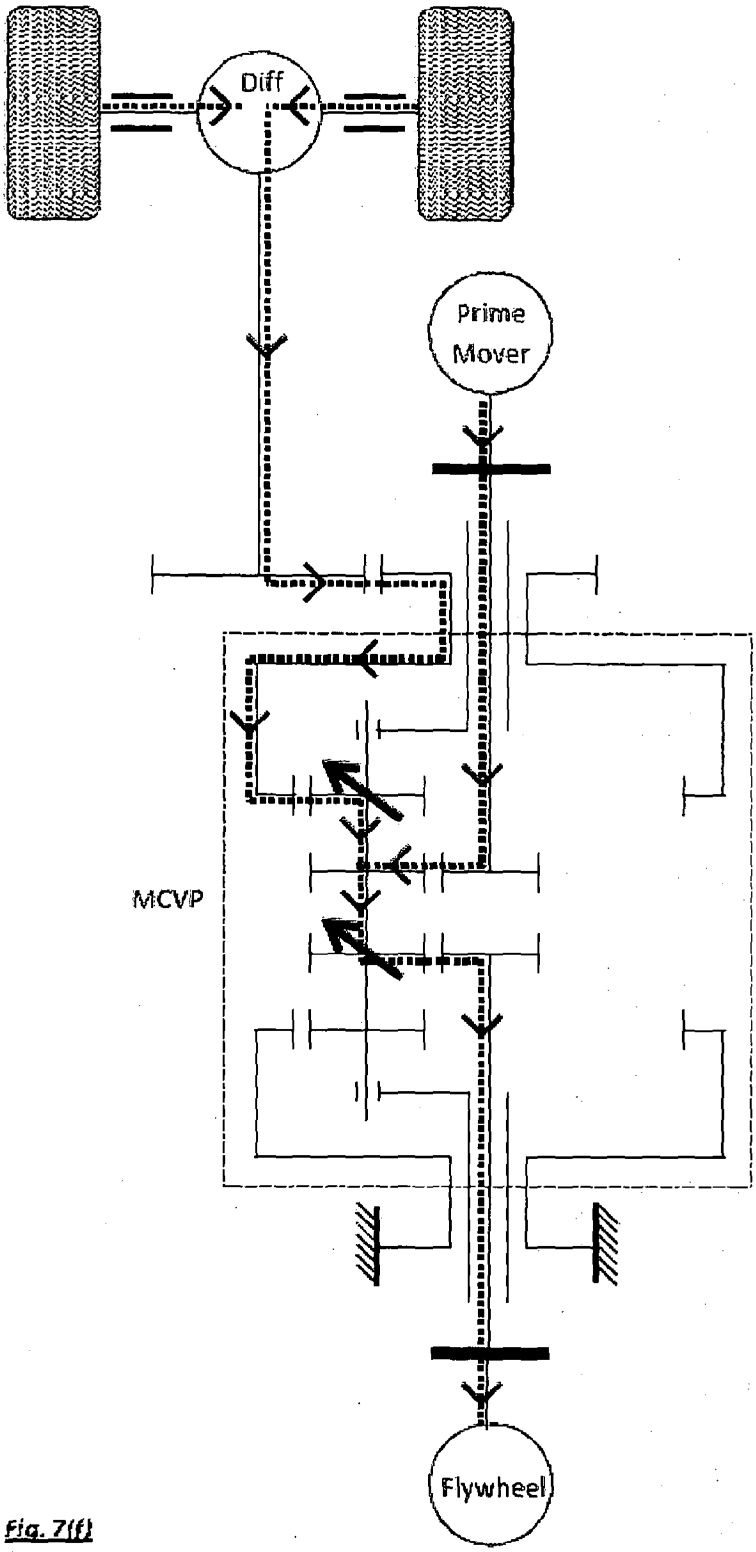


Fig. 7(e)



Regenerative braking and simultaneous prime mover charging of flywheel (SP-KERS)

Fig. 7(f)

SUPPLEMENT

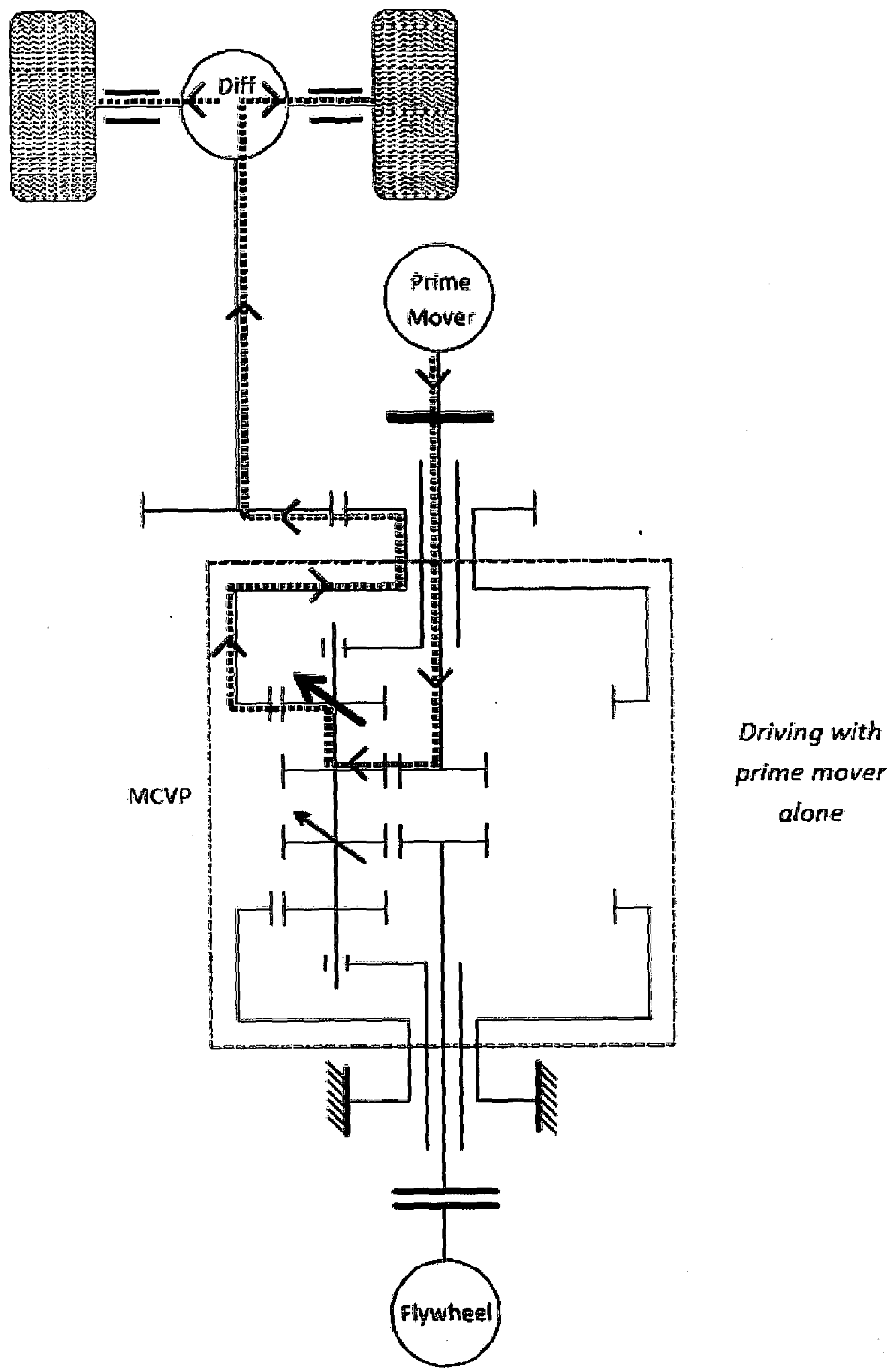


Fig. 7(a)

SUPPLEMENT

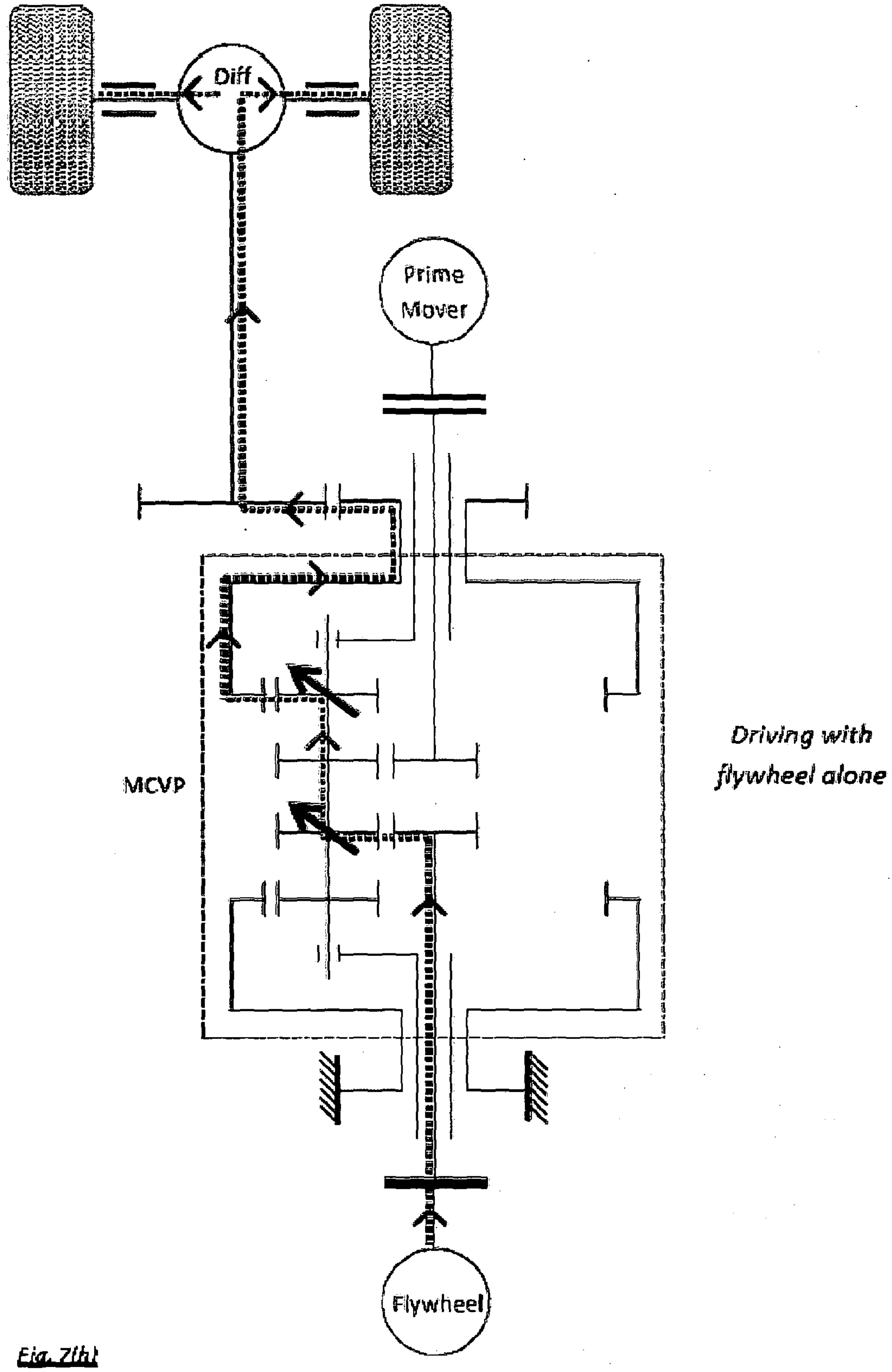


Fig. 7(h)

With reference to Figs. 8 to 10, one illustrative implementation of the teachings of the invention will now be described in more detail.

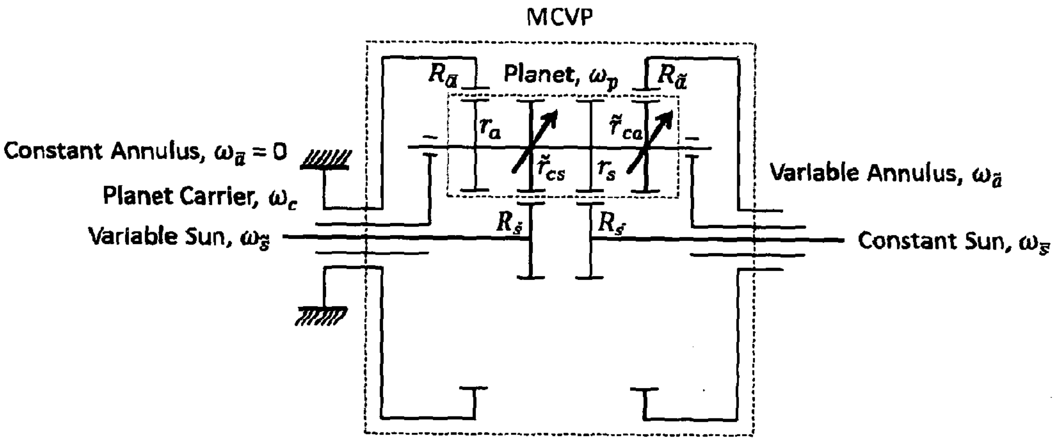


Fig. 8

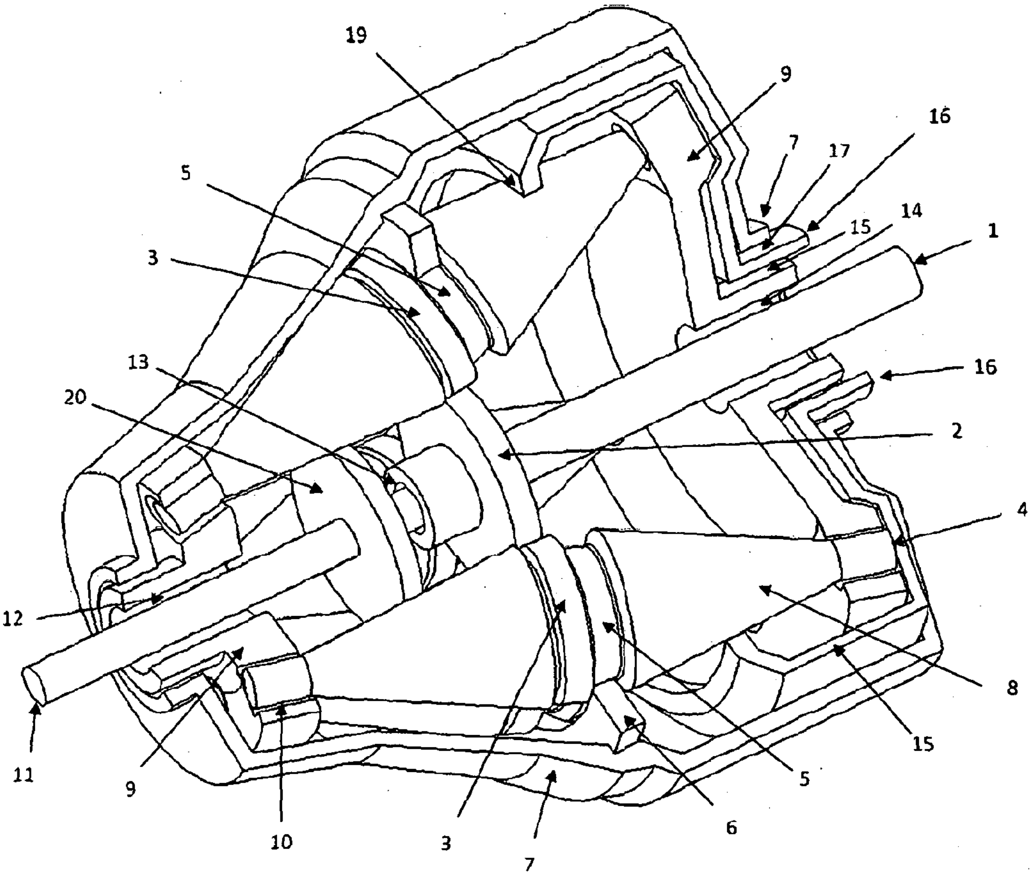


Fig. 9

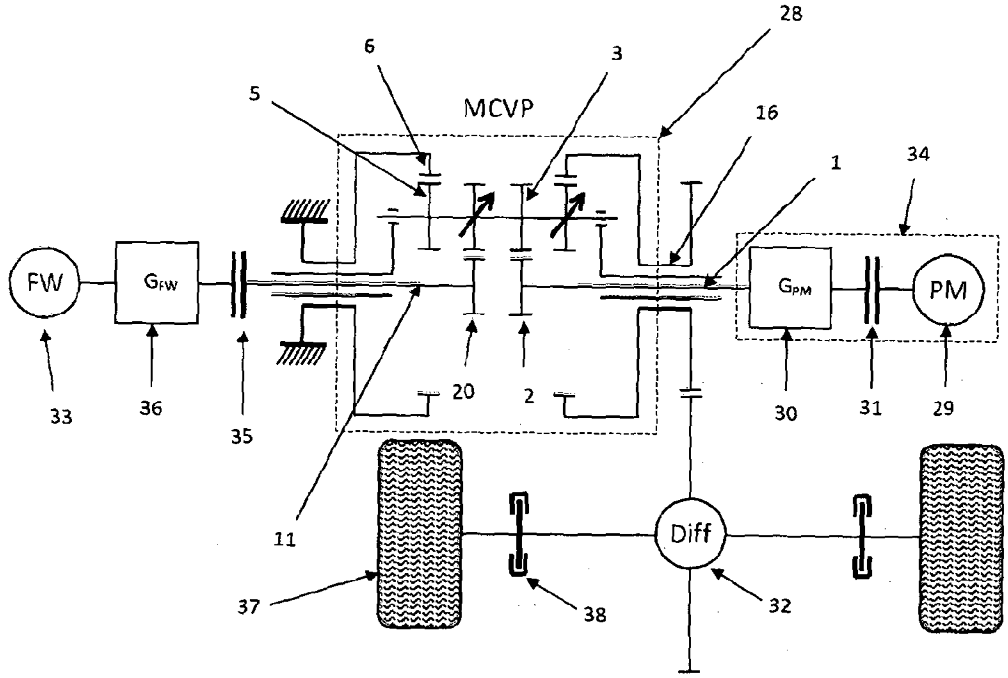


Fig. 10

Fig. 9 is an illustration of a variator configured as shown schematically in Fig. 8 where the constant annulus branch is fixed to ground. The final drive of the vehicle is connected to the variable annulus shaft, which gives IVT potential (including reverse, with the bias of the ratio spread being chosen to suit the application by suitable design selection of the variator radii shown in Figure 8).

The particur implementation shown in Figure 9 employs planets where the cones face base to base on the planet shaft. The two cones may, in another envisaged implementation, be arranged such that they may face tip to tip or in the same direction. The former arrangement would allow the diameter of the constant annulus to be reduced (which reduces the rotational stresses for the same shaft angular speed), the latter would mean that either both of the sun branches or both of the annuli branches would be variable.

Generation of the normal forces in the traction fluid contact patches required for efficient torque transfer is not so straight forward in this present embodiment of the invention, since the carrier is rotating. Planets may be inclined at an angle that is deliberately greater or smaller than the half cone angle so that an increasing interference as the contact disc/annulus moves in a direction of increasing (steady state) torque (i.e.

reduction in speed output shaft speed, and hence increase in torque for the same power). This is a passive system, meaning it does not require any external control. Another passive method would be elastically straining the disc/annulus that make traction contact with the conical planets, where this strain creates further interference and hence generates normal pressure on the fluid which increases with applied torque. The system may be bi-directional so that two similar mechanisms are used to act in opposite directions to create pressure from reversing torque. There would be backlash in this system as one mechanism relaxes whilst the other tenses when the direction of torque reverses.

The prime mover is connected to the constant sun shaft 1, to which is attached a bevel gear 2 (the constant sun gear) which meshes with a set of planet bevel gears 3 which are located in this embodiment at the axial centre of the planet 4 (one for each planet). Also on each planet 4 is another bevel gear 5 which meshes with an internal bevel gear 6, which is the constant annulus shaft (non-rotational in this embodiment since this branch is fixed to the casing 7). It will be appreciated by those experienced in the art that the bevel gears on the planets can be positioned in various places along the planet axis, such as between the cones 8 as shown or either side to achieve the same functionality and that the choice will ultimately be made by the constraints of the assembly. The planets are supported in a planet carrier 9 using bearings 10. The carrier is free to rotate in this particular implementation, but may be used as an input/output shaft in other implementations.

The input to the variator from the flywheel is connected to the variable sun shaft 11 which is supported by bearings 12, 13 in the carrier 9 and constant sun shaft 1 respectively. The constant sun shaft 1 may be supported by bearings 14 in the carrier 9 which is in turn supported by bearings 15 in the hollow variable annulus shaft 16. The variable annulus shaft 16 is geared to the final drive of the vehicle. The variable annulus shaft 16 is supported by bearings 17 in the casing 7. A beneficial feature of this arrangement is that all input/output shafts and the carrier rotate in the same direction and so the bearings only run at the difference between the shaft speeds, so the speed rating requirement for the bearings is not especially high despite the fact that the shafts may be running at high speed (absolute). This reduces the machining precision required for these bearings and hence the cost.

The variable annulus shaft 16 requires a mechanism allowing axial shifting of the annulus 19 making traction contact with the planet cone 7 in order to change the speed ratio between the prime mover and the vehicle. The variable sun shaft 11 also requires a mechanism to axially shift the variable sun disc 20 in order to change the speed of the flywheel relative to the prime mover/vehicle. These two variable branches may utilise techniques such as those employed in the Turbo Trac variator (see patent nos. US6001042 & US7856902) to facilitate this ratio control.

The bevel gears 2, 3, 5 and 6 may be spiral bevel gears to reduce noise and vibration and provide smooth torque transfer and increased fatigue life for the gear teeth and surfaces. Klingelnberg spiral bevel gears (where the teeth are not tapered) in particular may be used which can be generated with a hobbing process much like automotive gearboxes and hence benefit from low cost in volume production despite their seemingly complex geometry. Palloid tooth form may also be produced by hobbing but has greater bending strength since the teeth are tapered.

Figure 10 is a schematic representation of a transmission that incorporates the variator of Figs. 8 and 9. The variable annulus shaft 16 is hollow, allowing the constant sun shaft 1 to pass through coaxially on the same side of the variator 28, being connected to the prime mover 29 via a gearbox 30 and a clutch 31. This arrangement conveniently allows the differential 32 to be placed in the middle of the vehicle's powered axle, between the prime mover 29 and the variator 28, since this is permitted by the relative sizing of the prime mover, variator and flywheel. The prime mover 29, gearbox 30 and clutch 31 may be a standard automotive or motorbike engine and gearbox arrangement 34 with the included clutch 31. The flywheel 33 is connected to the variable sun shaft 11 via a clutch 35 and a gear box 36; order of said clutch and gearbox in the torque path is chosen for ease of component design/selection. The gearbox 36 may be a single fixed ratio, or a plurality of selectable ratios in order to behave as a ratio range extender for the flywheel branch of the variator, which can be appreciated by those skilled in the art. The range extender may have the capability to change gear without torque interruption (such as, but not limited to, dual or multiple clutch gearboxes) so as to allow continuous charging and discharging of the flywheel over a large range of vehicle/prime mover speeds.

In the arrangemend depicted in Figure 10, all shafts are parallel to the axle of the vehicle (they run transverse/across the vehicle). If the flywheel gearbox 36 does not reverse the rotational direction relative to the variable sun shaft 11, the flywheel 33 rotates in the same plane as the wheels 37 but in the opposite direction. This causes the reaction to the flywheel gyroscopic moments acting on the vehicle during cornering to counteract vehicle roll which adds stability to the vehicle and also reduces the net loss of tyre traction due to lateral load transfer. This feature is of particular benefit to racing applications, but also to road cars. If the flywheel gearbox does reverse the direction of rotation, then this can be counteracted by first ensuring the flywheel is in the correct orientation to rotate oppositely to the wheels, then selecting a gearing arrangement that will ensure the correct direction of shaft rotation at the vehicle wheels, whilst ensuring the drive from the prime mover is also in the correct rotational direction.

Mechanical brakes 37 can bring the vehicle safely to rest in event of failure of any control critical components in the transmission. The flywheel and prime mover clutches 35, 31 are simply disengaged in order to stop supply of power to the vehicle.

Fig. 11 is a schematic representation of a variator of the type disclosed herein mated with a 4-stroke 250CC prime mover and a flywheel.

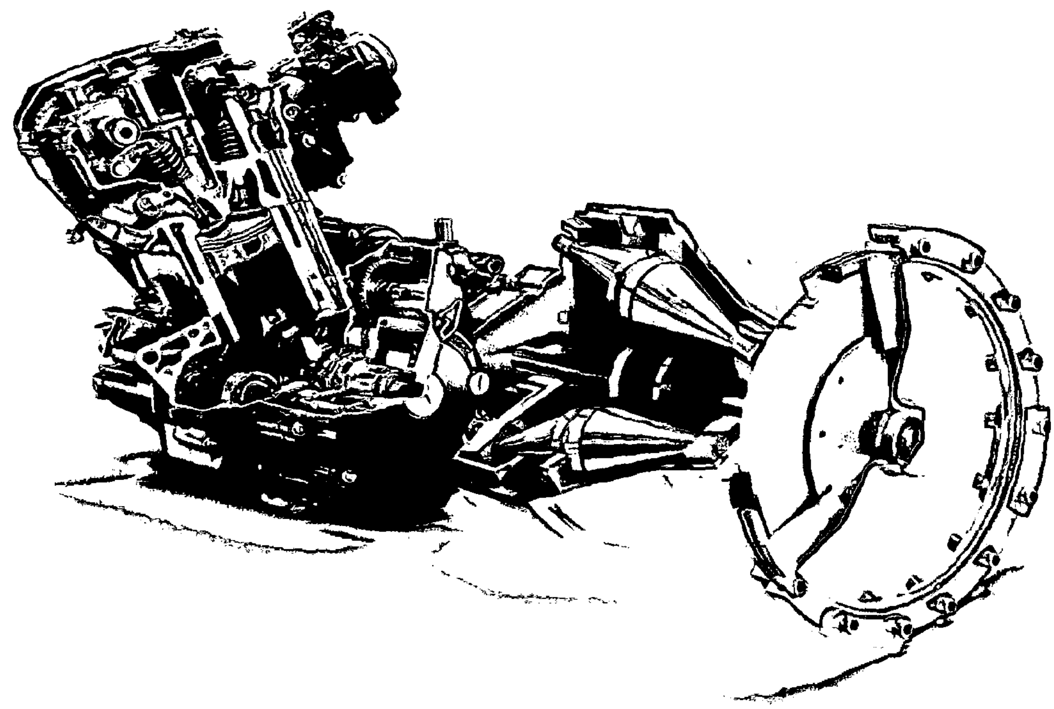


Fig. 11

Further details of the arrangements described herein may be found in the attached "appendix", which appendix is intended to be an integral part of this description so that subject matter disclosed therein may be freely combined with subject matter disclosed in the description provided above, and vice versa.

In very general terms, the various arrangements disclosed herein provide the following benefits.

New variator (MCVP):

- Provides two independent ratio control mechanisms whilst all power paths effectively only cross a single CVT, thereby providing improved flexibility and increased transmission efficiency.

- Mass savings may be made by effectively providing two CVTs in one assembly with common components shared between them.
- Planetary gear set similarities provide improved functionality as compared to existing planetary multiple input CVTs by adding at least one extra "branch" (5 in total), with two suns and two rings. Providing two similar type of branches e.g. suns is very useful and provides an improved choice of ratios and configurations (even in conventional one input / one output form) and by having independent ratio control.
- Simple (hence less expensive) geometry to manufacture

Transmission:

- Improved control strategy and operating mode flexibility than current flywheel hybrid systems (at a potentially lower or similar cost by obviating the need for a normal gearbox; and flywheel CVT combined with the main vehicle transmission)
- Ability to isolate the engine from road conditions and instantaneous power required by vehicle, thus can run constantly (and efficiently) like a series hybrid. Thus providing the possibility of reducing transient engine emissions thereby allowing diesels to meet emissions regulations without compromising performance.
- Reduces the effective mass of the vehicle (inertia of rotating components, especially of the engine) and therefore increases acceleration response per unit engine size.
- Increases possible deliverable power like an electric parallel hybrid by using flywheel, but less expensive and recyclable.
- IVT powered neutral possible with other shafts than engine remaining active and other ratio mechanism operational, so another component can be powered or a flywheel charged rather than wasting energy in power recirculation.
- Useful in cars, buses, vans, off-highway vehicles (such as tractors, diggers etc)
- Particularly good for vehicles with heavily transient power requirements (such as city buses that repeatedly stop and start, and racing vehicles) allowing flywheel to buffer constant power supplied by prime mover.

It will be appreciated that whilst various aspects and embodiments of the present invention have heretofore been described, the scope of the present invention is not limited to the particular arrangements set out herein and instead extends to encompass all arrangements, and modifications and alterations thereto apparent to a person of ordinary skill in the art. For example, whilst a flywheel has been employed in the arrangements described above it will be apparent that other motive power sources may instead be employed without departing from the scope of the present invention.

It should also be noted that the applicant specifically claims protection for any combination or permutation of features herein disclosed.

SUPPLEMENT

APPENDIX

TRANSMISSION SYSTEM

The following academic paper provides further details of the various different arrangements that are disclosed in United Kingdom Patent Application No. 1209265.5 (filed on 25 May 2012), the entire contents of which are incorporated herein by reference.

ABSTRACT

A patent-pending multiple-input continuously variable planetary traction drive with two independent ratio control mechanisms has been presented. A particular configuration suitable for use in hybrid vehicles has been identified and discussed. This configuration is shown to yield novel functionality and provide the full range benefits associated with series and parallel electric hybrids, but with a fully mechanical system using flywheel energy storage.

Like many new vehicle technologies, the proposed transmission has arisen from design work for a racing application but the key features of the system make it suitable for a wide range of ground vehicle applications. This includes large off-highway diesel-powered vehicles, which would benefit from the elimination of unfavourable transient diesel emissions offered by the proposed system.

INTRODUCTION

RACING REQUIREMENTS

The drive cycle of a typical lap of the endurance race is shown in Figure 1. It is notable that the vehicle is always accelerating or decelerating, never travelling at a constant speed, which is to be expected of a racing vehicle negotiating a winding track. On this drive cycle, around 70% of the total energy spent at the wheels is ultimately dissipated (wasted) as heat in the vehicle brakes. Therefore an effective kinetic energy recovery system (KERS) is an excellent way of increasing the overall efficiency of the vehicle. It must be remembered that during braking a small portion of the vehicle's kinetic energy is lost to resistance forces and therefore cannot be recovered.

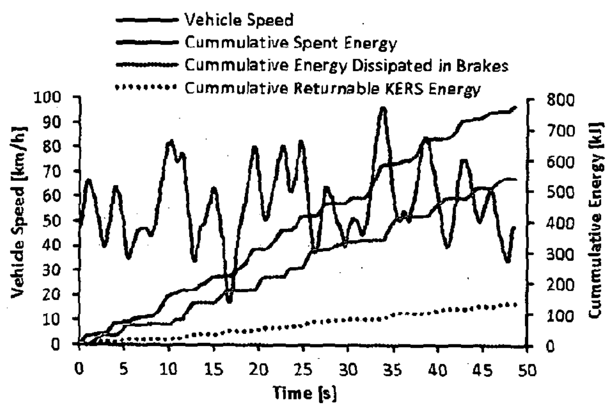


Figure 1: Drive cycle of an endurance lap showing cumulative braking energy and returnable KERS energy for mechanical system installed at rear axle

SUPPLEMENT

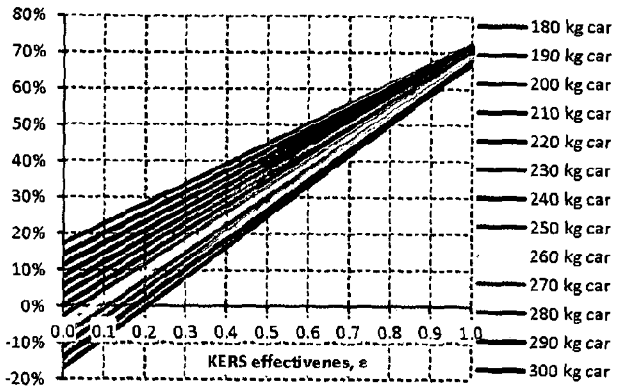


Figure 2: Energy saving relative to a 240kg baseline conventional vehicle (with 70kg driver)

Figure 2 shows the energy saving on the endurance drive cycle resulting from a KERS installation and/or increasing/decreasing mass of the vehicle. This graph was produced following similar calculation methods to Sovran [1].

EXISTING FLYWHEEL HYBRID SYSTEMS

The most mature flywheel-based hybrid systems with a mechanical transmission currently under development are apparently those of Flybrid Systems LLP. Their products advertised to date are systems designed to interface with a conventional road vehicle transmission (comprising a clutch, discrete gearbox and differential) without significant change to the transmission or general packaging of the vehicle.

Flybrid's original system was developed for Formula One, and has since appeared in a form optimized for road car applications. The system uses a high-speed flywheel connected to the vehicle transmission via a planetary gear set, a clutch, a torque-controlled Torotrak full-toroidal variator (CVT) and a second clutch [2].

A more recent product called the CFT (clutched flywheel transmission) approximates the CVT system by using a set of constantly meshed gear ratios and controlled slip of clutches to move between these fixed ratios in order to control flywheel energy storage and recovery. The CFT hybrid system is inserted between the clutch and the gearbox of a standard vehicle transmission, which multiplies the overall number of ratios available between the flywheel and the wheels, minimizing clutch slip and associated losses. This system was designed with smaller, low-powered vehicles in mind, where a CVT system would potentially be less efficient at such low power levels [8].

MULTIPLE-INPUT PLANETARY VARIATORS

There are two known prior art variators that possess some of the useful features of planetary gear set (PGS); the NuVinci CVP (continuously variable planetary) and the Milner CVT. Both of these variators use spherical planets and are able to connect more than the conventional two branches (one input, one output), with a continuously variable ratio existing between all branches. The Milner CVT is the closest to the conventional PGS, since it has one sun, one annulus and one planet carrier branch.

Since actuation of the Milner CVT ratio alters the contact radius of the sun, the planets and the annulus simultaneously, it achieves a wider ratio range compared to the NuVinci CVP, where only the contact radii on the planet are altered. The NuVinci CVP typically has a ratio range from 0.5 to 2.0 whereas the Milner CVT can have a ratio range from around 0.6 to 3.8 [4][6].

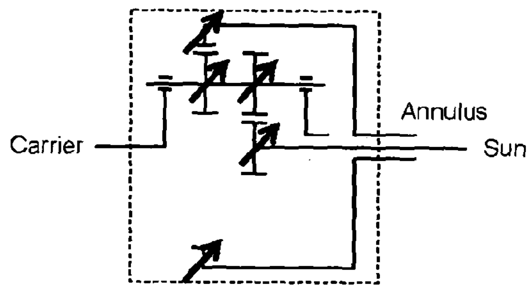


Figure 3: Milner CVT equivalent planetary schematic

The NuVinci CVP has two effective annuli branches, a sun and a planet carrier.

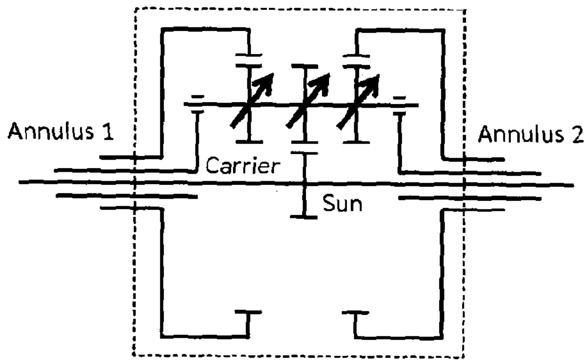


Figure 4: NuVinci CVP equivalent planetary schematic

Due to their similarities with the PGS, both the NuVinci CVP and Milner CVT have the potential to be used as a power-splitting device. The developers of both variators have acknowledged their potential for use in hybrid vehicles where more than one means of propelling a vehicle must be connected to a vehicle final drive. However, the focus has been only on electric hybrids and on the Toyota Hybrid System (THS) in particular, where both developers propose replacing the

SUPPLEMENT

conventional PGS with their power-splitting variator [4][5]. It seems from published literature that the use of multiple input variators has not been considered specifically for flywheel applications.

One reason for this may be the fact that actuation of the ratio control mechanisms of both the NuVinci CVP and the Milner CVT changes the ratio between all branches. The variable gear radii shown in Figures 3 and 4 all change simultaneously in varying degrees according to the respective geometrical relationships. Thus, when directly connecting two sources of motive power via either of these multiple input variators, simultaneous optimisation of the operating conditions of both sources is not easily achieved.

The ability to actuate two distinct mechanisms would be equivalent to having two independent variators within one component, providing the ability to independently choose the optimum speed ratio for two different means of propelling a vehicle. This would be useful in a multitude of applications, but is especially important for flywheel hybrids. The speed of the flywheel inherently changes during energy transfer (control of the flywheel speed controls the energy storage and recovery), since for a given flywheel inertia, the energy stored is purely a function of rotational speed; thus independent and continuously variable control of flywheel speed from the engine and the wheels is fundamental.

The ability of the present variator to provide independent ratio control of two branches within a single planetary arrangement has led to name of MCVP, meaning *Multi-Continuously Variable Planetary*.

MCVP VARIATOR

MCVP GEOMETRY

The MCVP is a new planetary traction drive using planets that are double truncated cones inclined at an angle to the main shaft axis equal to half of the cone angle (Figure 5). This produces two effective straight edges aligned parallel to the main axis of the variator. Two independent actuator mechanisms control the axial position of a disc and an annulus/ring (green contact patches) that make contact with the inner and outer effective edges of the planet. This changes the contact radius on the planet and thus the linear speed, changing the rotational speed of the said disc and annulus. The annulus and the disc rotate about the main rotational axis. Thus there are two independently controllable ratio mechanisms, which, as mentioned, is equivalent to having two independent variators.

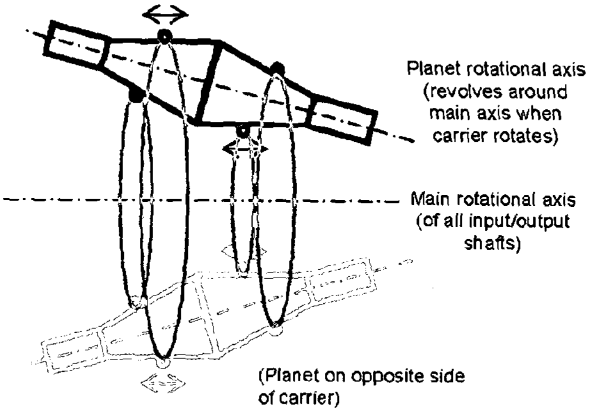


Figure 5: MCVP planets being double truncated cones

Precision manufacture of the conical surfaces is expected to be relatively inexpensive due to the relatively simple geometry compared to other existing variators. Mass and cost savings may be potentially made due to the fact that components are shared between the two effective variators. The fact that all branches (shaft inputs/outputs) of the MCVP are coaxial greatly aids producing a compact and torque/power-dense package.

MCVP EQUIVALENT SCHEMATIC

The analogous planetary representation of the MCVP is shown below, with the relevant gear pitch radii that appear in the equations.

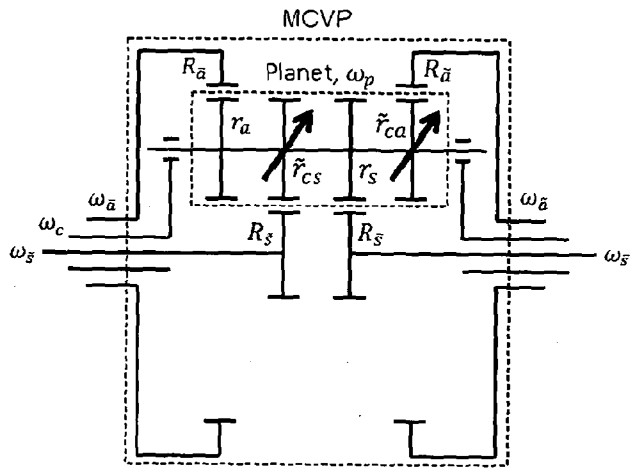


Figure 6: Equivalent compound planetary schematic for the MCVP

SUPPLEMENT

With regard to the equivalence of the MCVP to using two separate variators, higher transmission efficiency is expected here for certain power paths, which would otherwise involve crossing two separate CVTs and therefore be subject to the square of the efficiency of a single variator (see Figure 9 below).

Of fundamental importance, (in common with the Milner CVT and the NuVinci CVP) all the branches contact the same set of idling planet elements, therefore all possible power paths through the CVT cross a maximum of two traction contacts in series (effectively passing through a single CVT). Therefore, assuming efficient elasto-hydrodynamic conditions are generated at each of these contacts, higher transmission efficiency is expected compared to using two CVTs, where some power paths involve crossing two CVTs (which usually equates to 4 traction contacts in series). In general, traction contacts in parallel add linearly to the torque capacity of a CVT, but traction contacts in series reduce efficiency with a multiplicative relationship. The MCVP and the two prior art devices mentioned are advantageous in both of these regards.

MCVP MECHANICAL HYBRID TRANSMISSION

PREFERRED CONFIGURATION

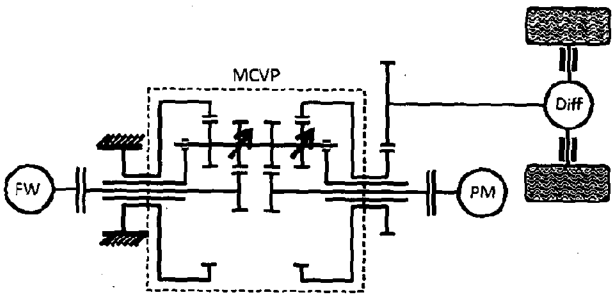


Figure 7: Full system schematic of proposed transmission

For the proposed mechanical hybrid transmission using the MCVP is shown in Figure 7 above. The flywheel is connected to the variable sun branch, the prime mover is connected to the constant sun branch, the final drive is connected to the variable ring branch and the constant ring branch is fixed to ground (no rotation). The carrier is necessarily free to rotate. The flywheel and the prime mover are connected to their respective branches by means of a clutch (as shown) but they may also require a fixed ratio gear stage (not shown) before or after the clutch in order to obtain the right speeds in the transmission.

KINEMATIC RELATIONS

These equations are ideal since they assume no slip occurs in the traction contact patches.

Variable sun branch

$$\frac{\omega_{\tilde{s}}}{\omega_{\bar{s}}} = \frac{\frac{\tilde{r}_{cs}}{R_{\tilde{s}}} + \frac{r_a}{R_{\bar{a}}}}{\frac{r_s}{R_{\bar{s}}} + \frac{r_a}{R_{\bar{a}}}}$$

Variable annulus branch

$$\frac{\omega_{\tilde{a}}}{\omega_{\bar{s}}} = \left[\left(\frac{\frac{r_s}{R_{\bar{s}}} + \frac{\tilde{r}_{ca}}{R_{\tilde{a}}}}{\frac{r_s}{R_{\bar{s}}} + \frac{r_a}{R_{\bar{a}}}}\right)\frac{r_a}{R_{\bar{a}}} - \frac{\tilde{r}_{ca}}{R_{\tilde{a}}}\right]\frac{R_{\bar{s}}}{r_s}$$

Planet carrier

$$\frac{\omega_c}{\omega_{\bar{s}}} = \frac{\frac{r_a}{R_{\bar{a}}}}{\frac{r_s}{R_{\bar{s}}} + \frac{r_a}{R_{\bar{a}}}}$$

For the racing application, it was desired to run a smaller engine in a constant condition in order to provide the same total delivered energy per lap but to provide fuel and mass savings. The mass saving is important as it offsets the added mass of the flywheel hybrid system.

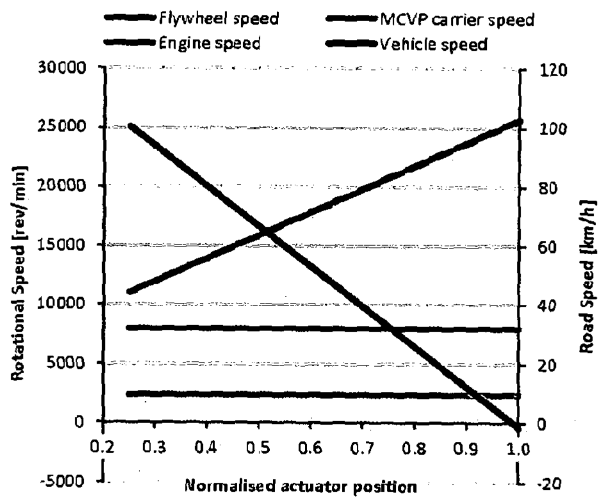


Figure 8: Speed ranges for flywheel and vehicle

As proposed by Genta [3], the usable storage of a flywheel lies between the maximum design speed and half of this value. Figure 8 above shows that this is achieved with the proposed system.

SUPPLEMENT

However, this is when the engine is kept running in a constant condition. If the engine speed reduces, the flywheel will not be able to reach its design speed of 25 000 rev/min. A range extending gearbox could be provided for the flywheel and/or other branches. This is effectively a discrete gearbox with a number of speed ratios that can be used in conjunction with the continuously variable ratio. A system like Flybrid's aforementioned CFT could be used for this purpose. This would allow all the benefits of the proposed system to be maintained but the ratio range for the flywheel would be increased. The same could be done for the final drive if necessary, to allow finer control of the vehicle speed. The use of the CFT system would mean that there would be no torque interruption when the range extending ratios are changed. This would also be the case with a dual clutch transmission used as a range extending gearbox.

The fact that these relations are linear makes for easier control of the system.

IVT FUNCTIONALITY

By examining the speed ratio equation for the variable ratio annulus branch, it is clear that this branch has a possible geared-neutral condition. This is when there is zero output speed for any finite input speed. This condition is achieved when the term in square brackets is equal to zero, which occurs when the following two quotients are equal:

$$\frac{\tilde{r}_{ca}}{R_{\tilde{a}}} = \frac{r_a}{R_{\bar{a}}} \Leftrightarrow \frac{\omega_{\tilde{a}}}{\omega_{\bar{s}}} = 0$$

Either side of this geared-neutral condition, the direction of rotation of the variable annulus branch reverses, providing the potential for reverse gear (if desired):

$$\frac{\tilde{r}_{ca}}{R_{\breve{a}}} > \frac{r_a}{R_{\bar{a}}} \Leftrightarrow \frac{\omega_{\tilde{a}}}{\omega_{\bar{s}}} < 0$$

$$\frac{\tilde{r}_{ca}}{R_{\breve{a}}} < \frac{r_a}{R_{\bar{a}}} \Leftrightarrow \frac{\omega_{\tilde{a}}}{\omega_{\bar{s}}} > 0$$

Furthermore, the ratio spread between forward and reverse gear can be altered by appropriate selection of correlated values for r_a, $R_{\tilde{a}}$ and $R_{\hat{a}}$ at the design stage depending on the application. This is a useful feature of the MCVP, since off-highway vehicles such as tractors sometimes have equal ratios for forward and reverse, whereas a racing car does not require a reverse gear.

Continuously variable transmissions with this geared-neutral capability are otherwise known as an IVTs (infinitely variable transmissions). In common with other IVTs, the following benefits are thus gained by the proposed system. There is no need for a pulling away device such as a clutch or a torque converter. Any external torque applied at the vehicle wheels will not cause the vehicle to move, which provides an effective parking brake when the vehicle is stationary on an inclined road.

There is, however, a novel feature of this IVT system that is very important, which is that all other branches of the system remain rotational, and actuation of the other ratio control mechanism provides full continued functionality for that respective branch independent of the geared-neutral condition of the final drive. This allows the flywheel to be charged with prime mover power by actuating the other ratio mechanism so as to increase the flywheel speed. In conventional IVT systems in geared-neutral mode, the power is just recirculated and ultimately dissipated (wasted) as heat in the transmission. In the present system it may be stored for later use, thus increasing system efficiency. As the vehicle pulls away, the torque subtracted from the transmission by increasing the flywheel speed is controllably reduced.

OPERATING REGIMES

The most important operating regimes for the system are shown with the aid of power flow diagrams in the Appendix, in Figures A1 to A8. A key to the symbols used is presented in Figure A0

The proposed system has exactly the same functionality as the transmission shown in Figure 9 below, and reference shall be made to this figure in explaining how the proposed system is able to accomplish simultaneous regenerative braking (kinetic energy recovery) whilst simultaneously charging the flywheel with surplus engine power. This feature is required if the engine is to run in a constant condition as the vehicle operates.

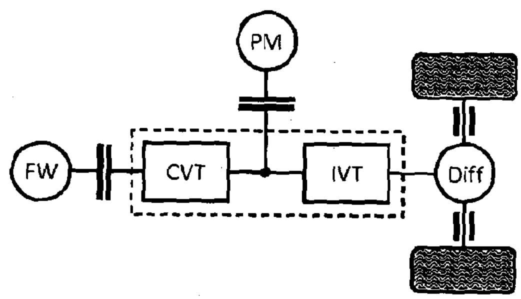


Figure 9: Equivalent system using two separate variator

Forcing a change in the CVT ratio such that the flywheel speeds up creates a negative torque on the transmission. If this torque is equal to a positive torque applied to the transmission by changing the ratio of IVT such that the vehicle speed reduces, the kinetic energy

SUPPLEMENT

and momentum are exchanged between the vehicle and the flywheel. If the engine is also supplying torque (positive) and the CVT ratio is changed such that this torque is also consumed by the changing the flywheel speed, then the flywheel is being used to accept the vehicle kinetic energy and the engine power at the same time.

The system behaves like an electric series hybrid, in that the engine can run in an efficient regime, but without the associated energy conversion losses from mechanical to electrical to chemical potential and back again. It also behaves like a parallel hybrid in that the flywheel can add power to the transmission such that more power is being supplied than that by the engine alone (Figure A4).

When the engine is running in a constant condition, the flywheel can accept surplus engine torque to prevent the wheels from slipping at low speed (Figure A3).

CONCLUSION

A novel multiple-input variator with two independent ratio control mechanisms has been presented. A mechanical hybrid transmission using flywheel energy storage centred around this variator has been proposed. The system provides the operational flexibility associated with using two separate CVTs for the prime mover and the flywheel, but achieved with a single variator. This provides a wide range of potential control strategies and effectively provides a mechanical equivalent to electric series and parallel hybrids. However, since the energy is not converted to different forms, the proposed solution has the potential to be more efficient. Furthermore, power flow between any two branches effectively only crosses a single CVT per one way trip and therefore relatively high mechanical transmission efficiency may result.

Being a fully mechanical solution, added value to the cost of materials in mass production is relatively high. Tthe cost per unit should reduce significantly relative to battery electric hybrids when produced in reasonable volumes, since it only requires the use of widely available and recyclable materials (such as steel and aluminium) and can make use of mass production forming processes (such as casting for the casings). At the end of life, the system can be melted down and the materials fully reused for another purpose.

Thus the proposed system potentially provides a more sustainable and low cost alternative to electric hybrids whilst retaining all the beneficial features, such as efficient combustion engine operation, power assistance, potential for engine stop-start and kinetic energy recovery.

A scaling analysis of the variator is currently being undertaken to assess what the optimum design parameters are for a given application. More detailed dynamic simulation is intended along with accurate mathematical models for the elasto-hydrodynamic (EHL) loss mechanisms within the variator.

REFERENCES

1. Sovran, G., "The Impact of Regenerative Braking on the Powertrain-Delivered Energy Required for Vehicle Propulsion" SAE Technical Paper, 2011-01-0891, 2011, doi: 10.4271/2011-01-0891
2. Cross, D., Brockbanck, C., "Mechanical Hybrid System Comprising a Flywheel and CVT for Motorsport and Mainstream Automotive Applications" SAE Technical Paper, 2009-01-1312, 2009, doi: 10.4271/2009-01-1312
3. Genta, G., "Kinetic Energy Storage: Theory and Practice of Advanced Flywheel Systems", Butterworths, London, ISBN 0408013966, 978-0408013963, 1985
4. Moyers, J., Akehurst, S., Parker, D.A., Schaaf, S., "The Application of the Milner CVT as a Novel Power Splitting Transmission for Hybrid Vehicles", SAE Technical Paper, 2011-01-0890, 2011, doi: 10.4271/2011-01-0890
5. Pohl, B., Simister, M., Smithson, R., Miller, D., "Configuration Analysis of a Spherical Traction Drive CVT/IVT", SAE Conference Paper, 04CVT-9
6. Smithson, R., Miller, D., and Allen, D., "Scalability for an Alternative Rolling Traction CVT," SAE Technical Paper 2004-01-0355, 2004, doi:10.4271/2004-01-0355
7. Carter, J. and Miller, D., "The Design and Analysis of an Alternative Traction Drive CVT," SAE Technical Paper 2003-01-0970, 2003, doi:10.4271/2003-01-0970
8. Cross, D., UK patent GB2476676B, published 7th Dec 2011

SUPPLEMENT

DEFINITIONS, ACRONYMS, ABBREVIATIONS

MAIN SMYBOLS:

ω: Angular speed

R: Perpendicular distance of centre of traction contact from *main rotational axis* of MCVP <u>or</u> pitch radius of constant sun/annulus teeth

r: Perpendicular distance of centre of traction contact from *planet rotational axis* <u>or</u> pitch radius of planet teeth

$\tilde{r}_c$: Contact radius on planet (perpendicular distance from planet axis) that can be varied by actuating ratio control mechanism

SUBSCRIPTS:

$\bar{a}$: Constant ratio annulus branch
$\tilde{a}$: Variable ratio annulus branch
$\bar{s}$: Constant ratio sun branch
$\tilde{s}$: Variable ratio sun branch

APPENDIX: OPERATING REGIMES & POWER PATHS

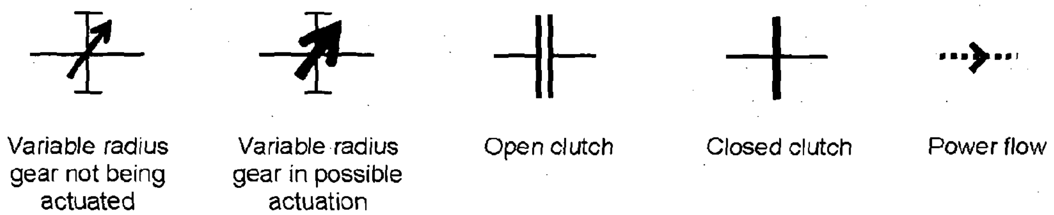


Figure A0: Key to symbols

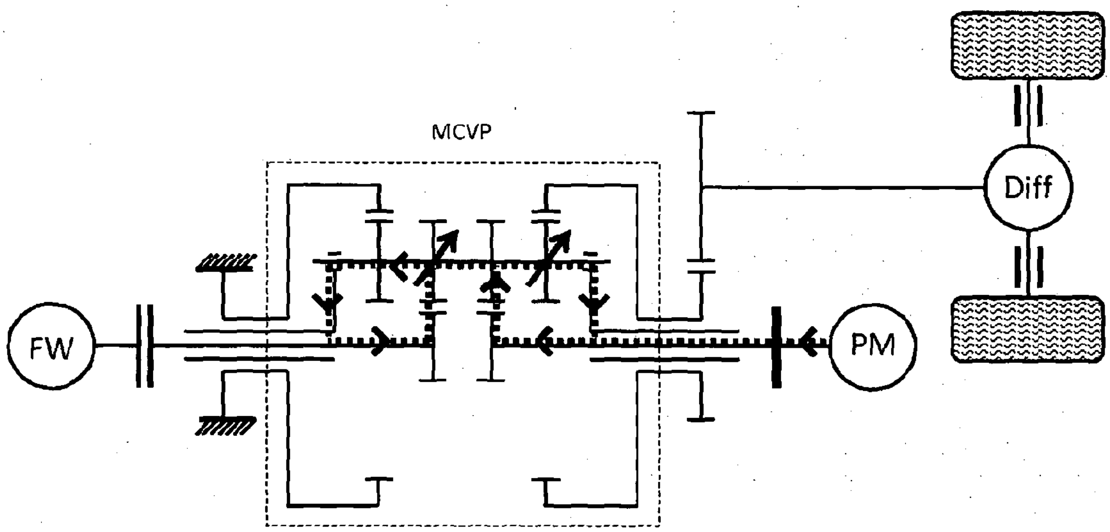


Figure A1: Conventional geared-neutral mode (power recirculated & dissipated as heat)

SUPPLEMENT

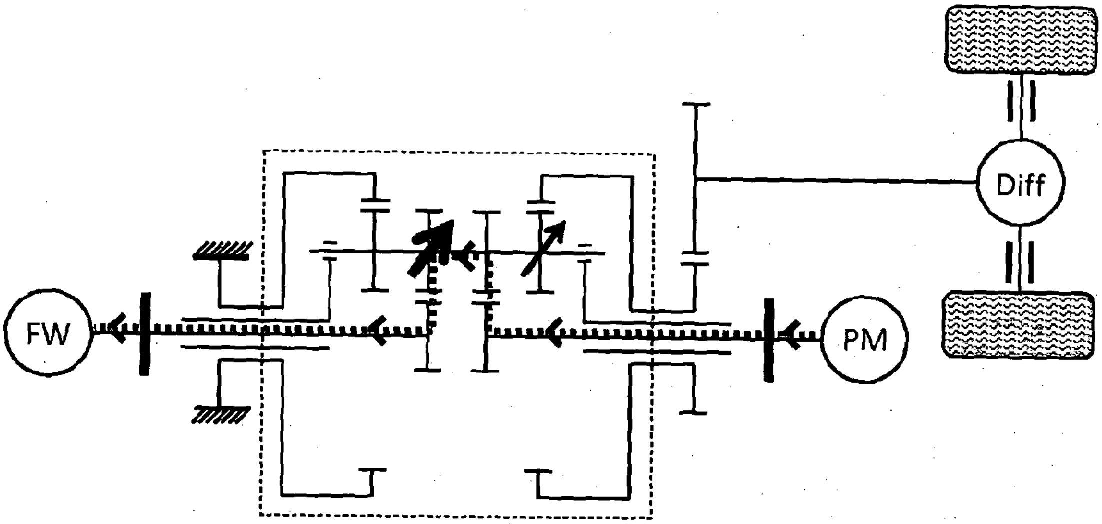


Figure A2: Charging of flywheel in geared-neutral mode

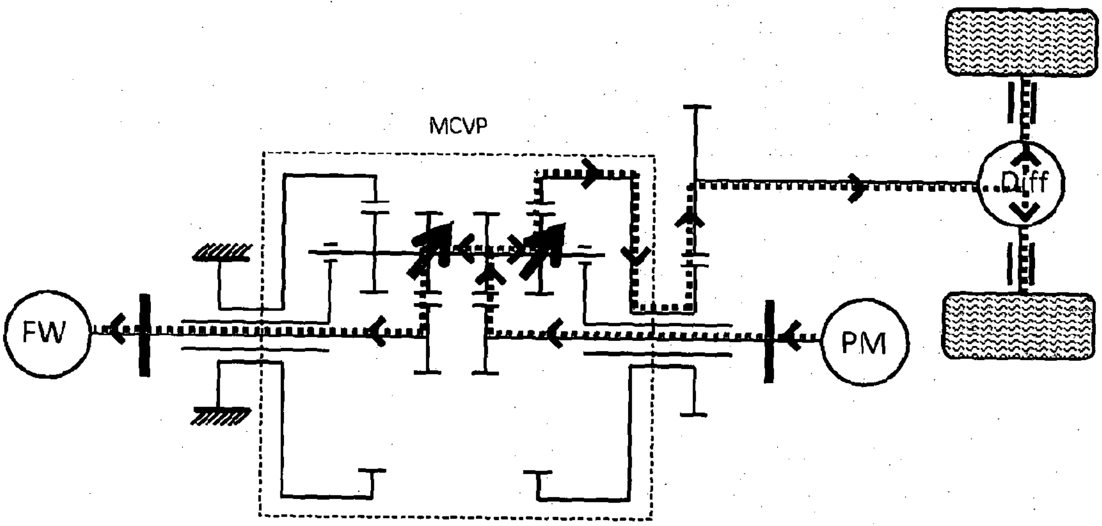


Figure A3: Surplus prime mover power (including traction-limited acceleration)

SUPPLEMENT

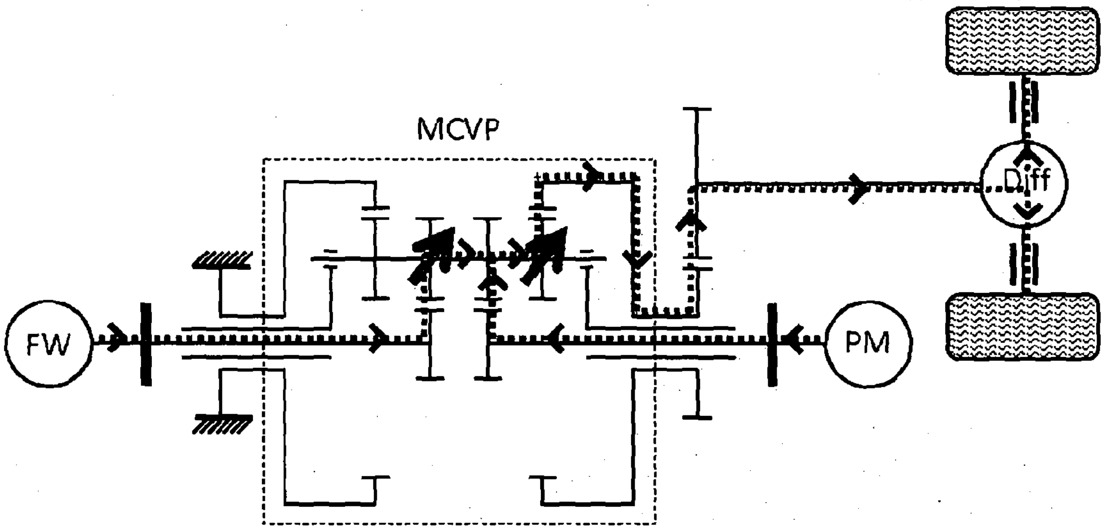


Figure A4: Insufficient prime mover power (including power-limited acceleration)

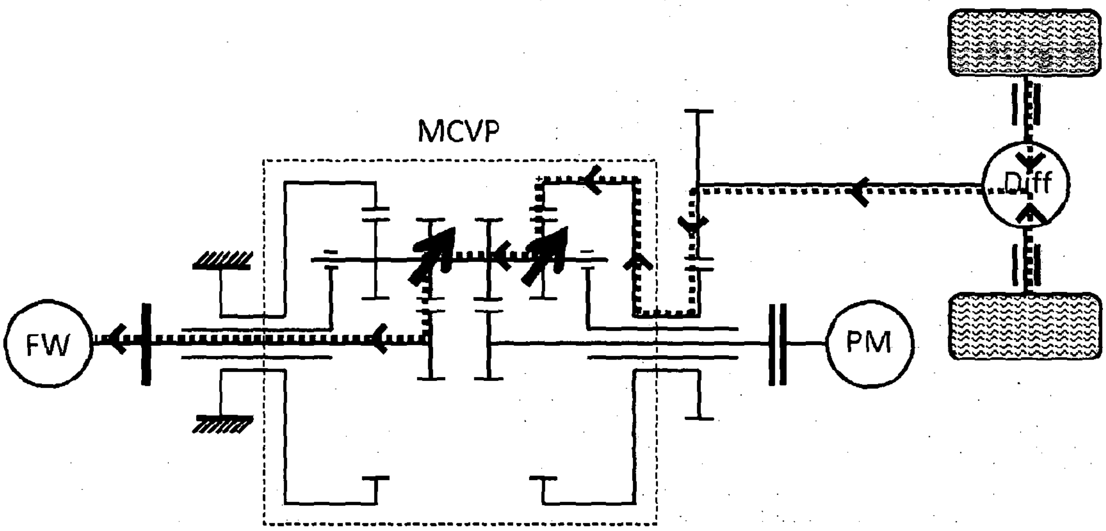


Figure A5: Pure regenerative braking

SUPPLEMENT

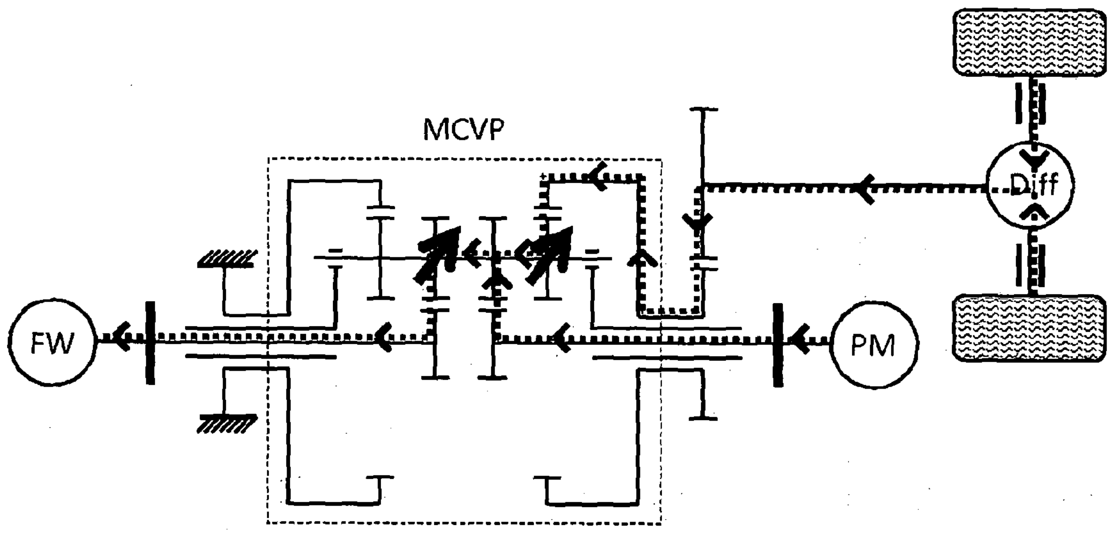


Figure A6: Regenerative braking and simultaneous prime mover charging of flywheel (SP-KERS)

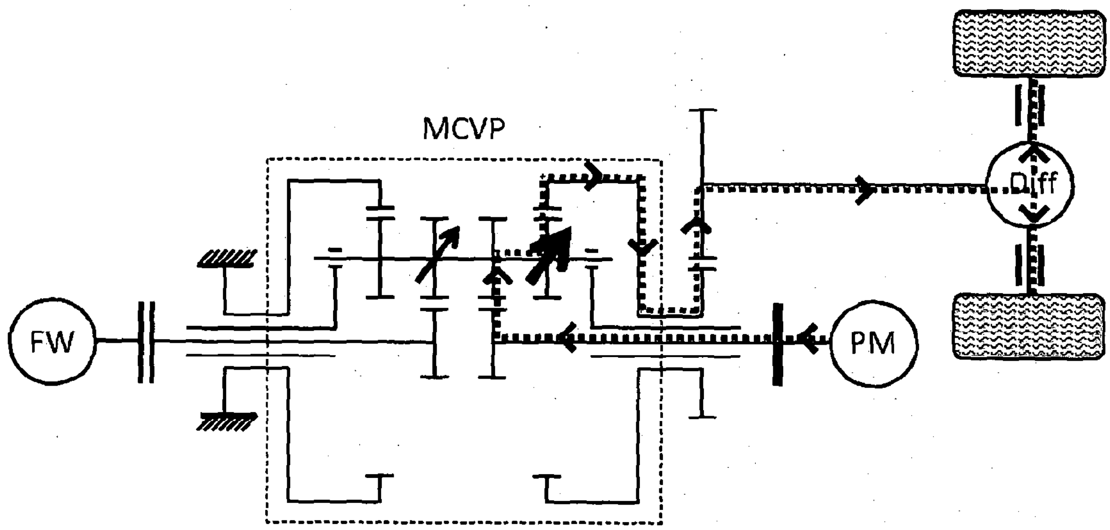


Figure A7: Driving with prime mover power alone

SUPPLEMENT

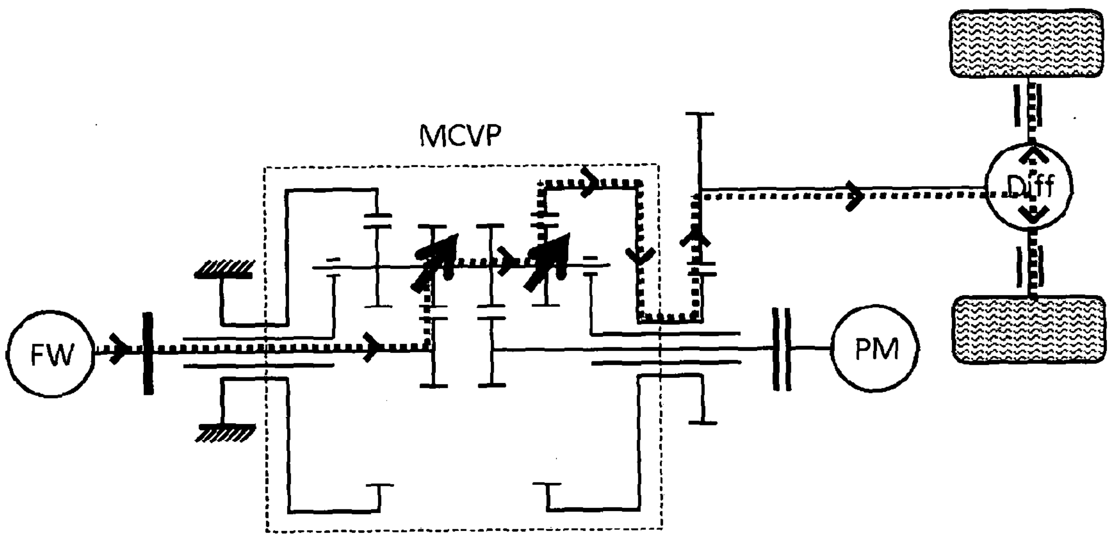


Figure A8: Driving with flywheel power alone

CLAIMS

1. A variator for a transmission system, the variator comprising: a first and a second cone, said cones being rotatable about a common axis that is inclined relative to a main axis so that said first and second cones each provide a contact surface that is substantially parallel to said main axis.

2. A variator according to Claim 1, further comprising a first actuator mechanism arranged to vary the axial position with respect to the main axis of a disc member which bears against said contact surface of said first cone.

3. A variator according to any preceding claim, comprising a second actuator mechanism arranged to vary the axial position with respect to the main axis of a second disc member which bears against said contact surface of said second cone.

4. A variator according to Claim 2 and Claim 3, wherein said first and second actuator mechanisms are controllable independently of one another.

5. A variator according to Claim 4, wherein movement of said first disc along said first cone contact surface changes a contact radius of said actuator on said contact surface and varies the rotation speed of said first actuator about said main axis.

6. A variator according to Claim 4 or 5, wherein movement of said second actuator along said second cone contact surface changes a contact radius of said actuator on said contact surface and varies the rotational speed of said second actuator about said main axis.

7. A variator according to Claim 5 or 6, wherein said first cone contact surface is radially closer to said main axis than said second cone contact surface.

8. A variator according to Claim 7, wherein said first actuator comprises a disk, and said second actuator comprises a ring.

9. A variator according to any preceding claim, wherein said first and second cones are mounted in a carrier that is rotatable around said main axis.

10. A variator according to any preceding claim, wherein said cones each comprise a

circular base and taper from said base towards a top portion so that the radius of said base is larger than the radius of said top portion.

11. A variator according to Claim 10, wherein said first and second cones are arranged so that the base of said first cone is adjacent the base of said second cone.

12. A variator according to Claim 10, wherein said first and second cones are arranged so that the top portion of said first cone is adjacent the top portion of said second cone.

13. A variator according to Claim 10, wherein said first and second cones are arranged so that the base of said second cone is adjacent the top portion of said first cone.

14. A variator according to Claim 10, wherein said first and second cones are arranged so that the base of said first cone is adjacent the top portion of said second cone.

15. A transmission for a vehicle, the transmission comprising a variator according to any preceding claim.

16. A vehicle comprising a transmission according to Claim 16, a primary source of motive power and a secondary source of motive power.

17. A vehicle according to Claim 16, wherein one of said primary and second sources of motive power comprises a flywheel.

18. A vehicle according to Claim 16 or 17 wherein one of said primary and secondary sources of motive power comprises an internal combustion engine.

19. A vehicle according to any of Claims 16 to 18, wherein one of said primary and secondary sources of motive power comprises a motor-generator.

20. A vehicle comprising a transmission according to Claim 16, a primary power sink and a secondary power sink.

21. A variator as substantially as hereinbefore described and with reference to the accompanying figures.

22. A transmission as substantially as hereinbefore described and with reference to the

accompanying figures.

23. A vehicle as substantially as hereinbefore described and with reference to the accompanying figures.

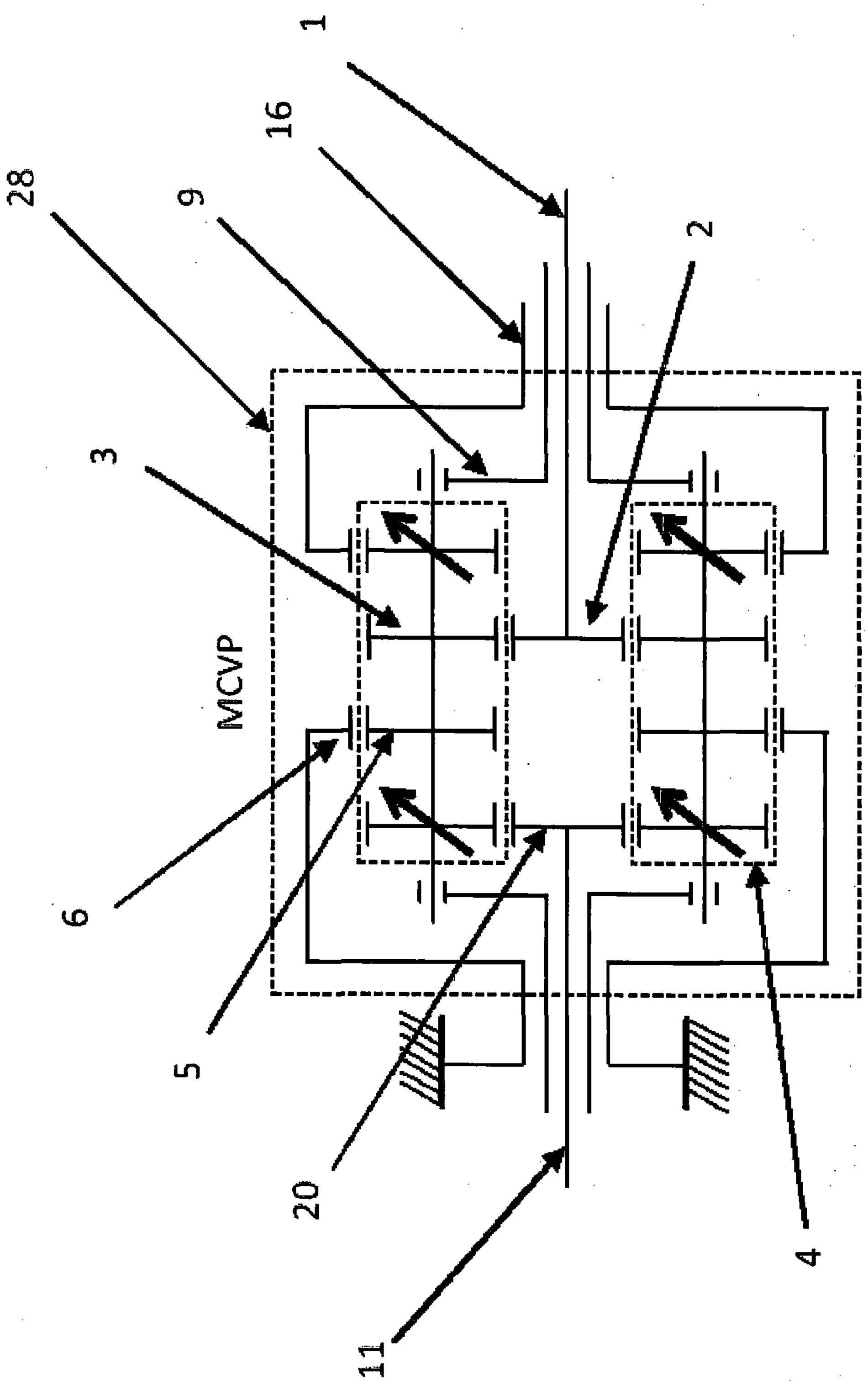


Fig. 1

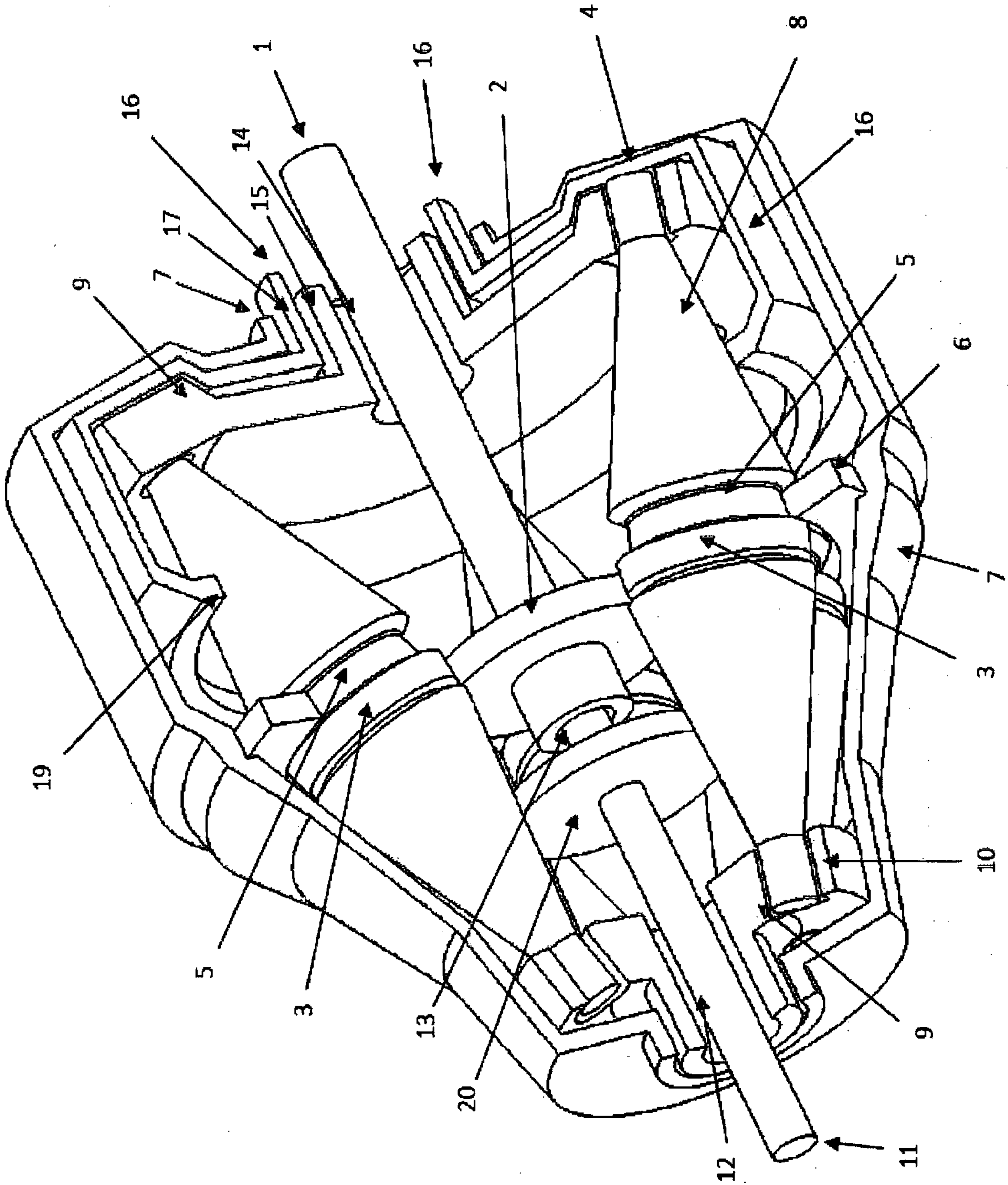


Fig. 2

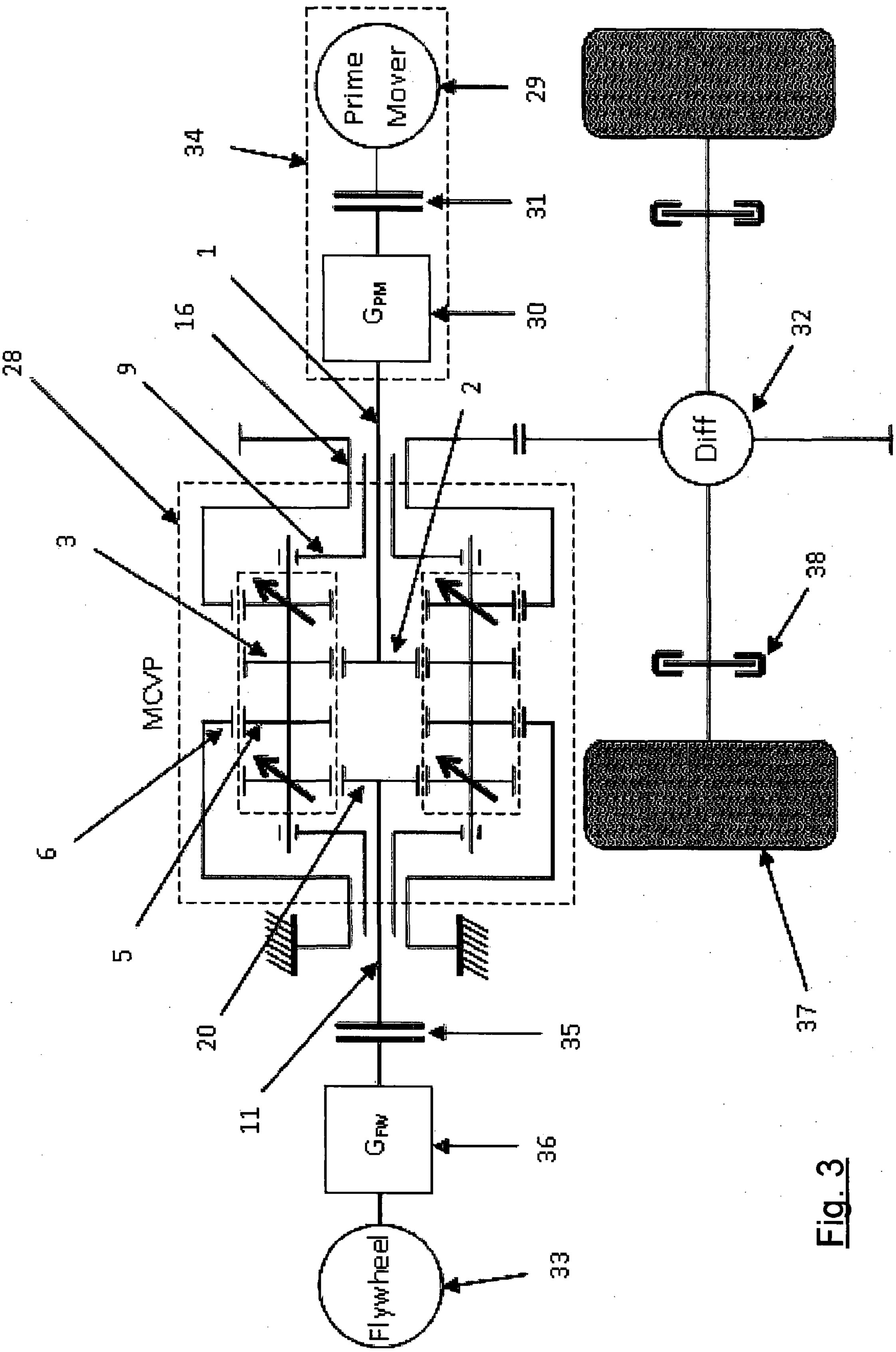

Prime Mover
G_PM
MCVP
Diff
G_FW
Flywheel
1
2
3
5
6
9
11
16
20
28
29
30
31
32
33
34
35
36
37
38

Fig. 3

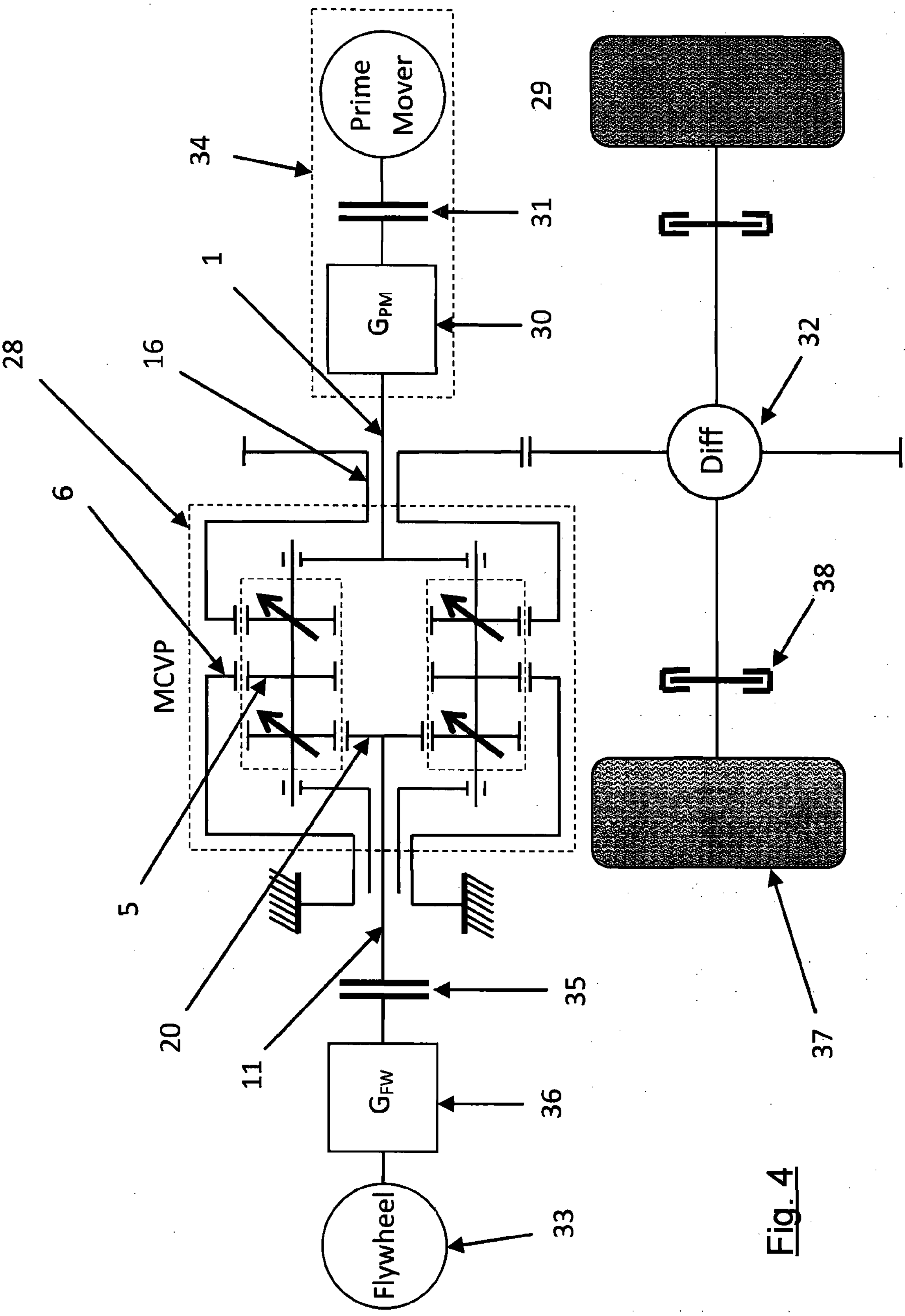

Prime Mover
34
31
1
G_{PM}
30
29
28
16
6
MCVP
Diff
32
38
5
20
11
35
G_{FW}
36
Flywheel
33
37

Fig. 4

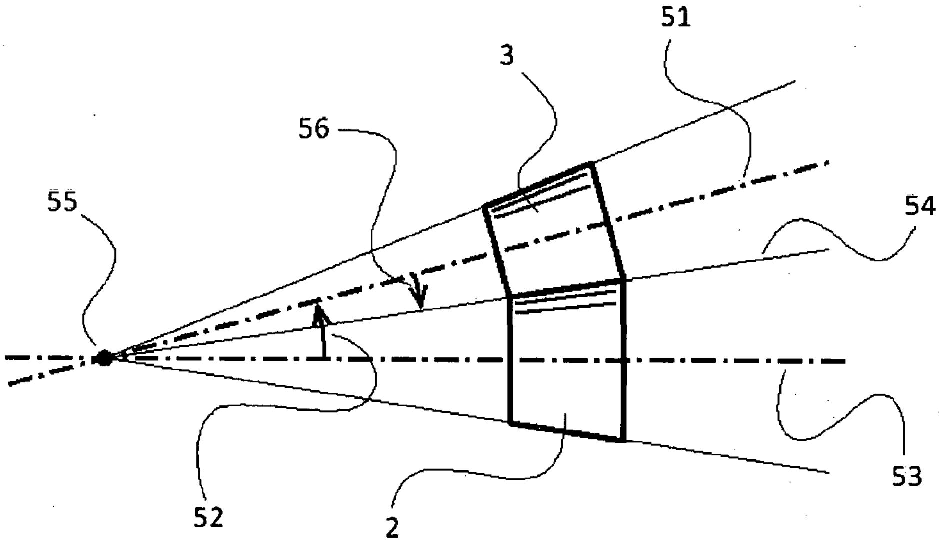


Fig. 5

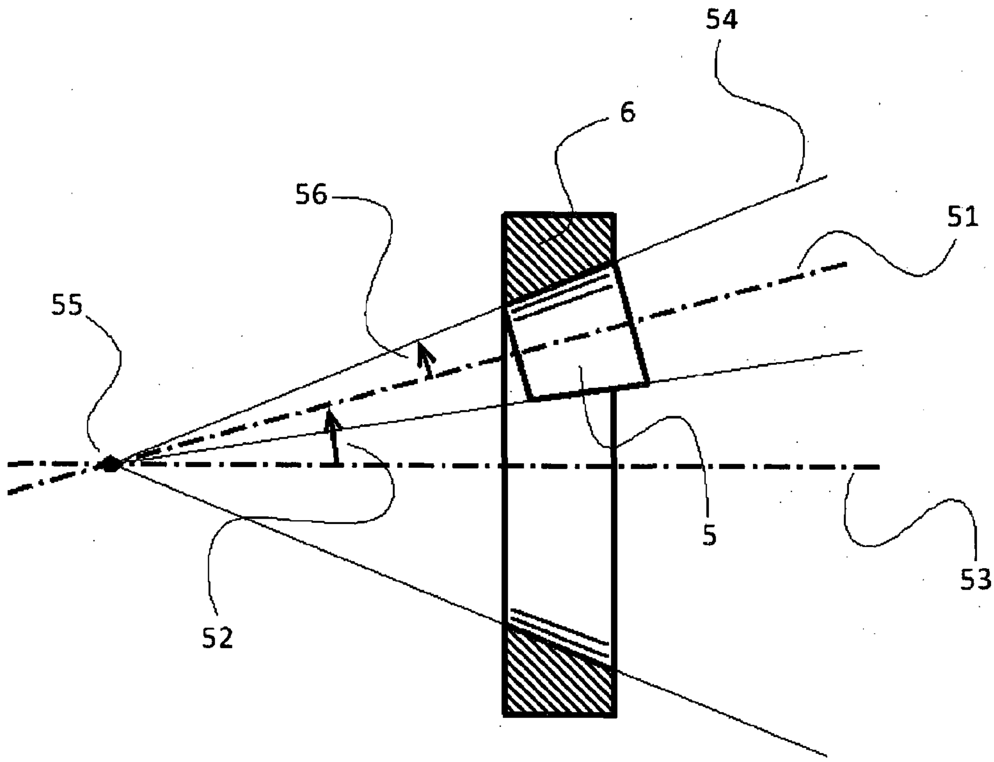


Fig. 6

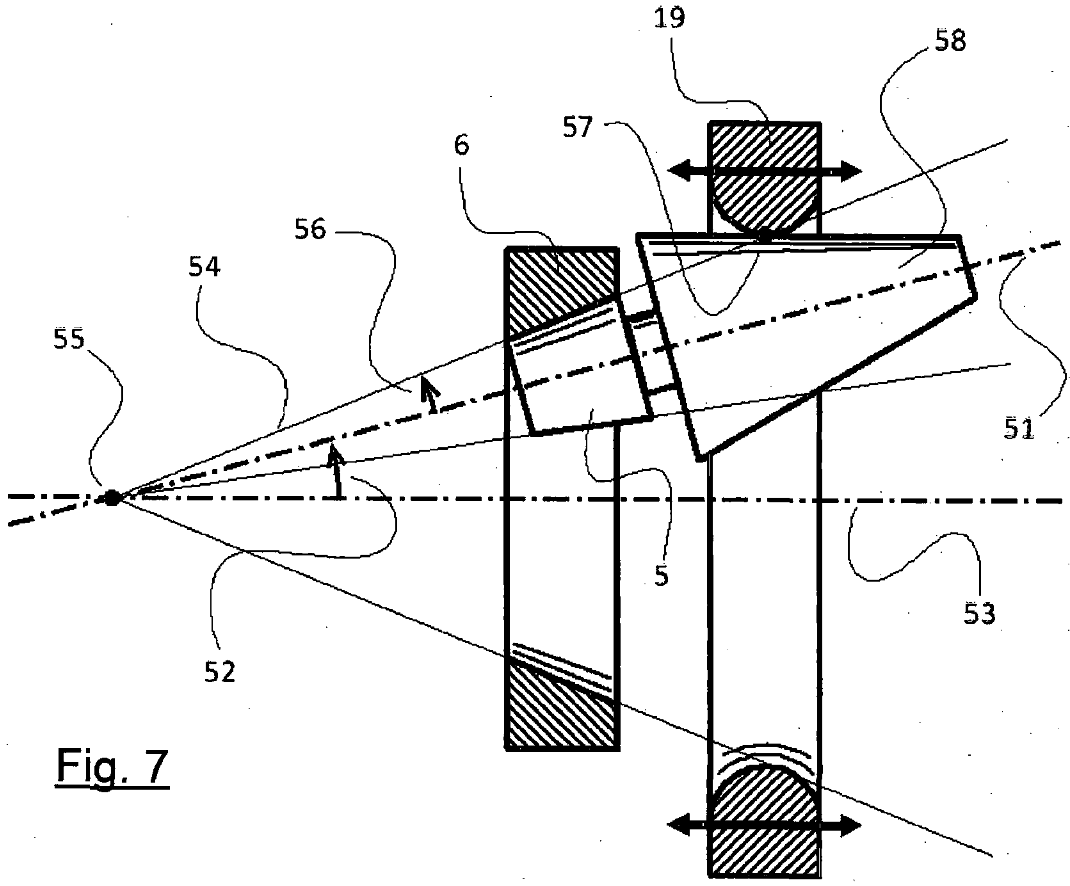


Fig. 7

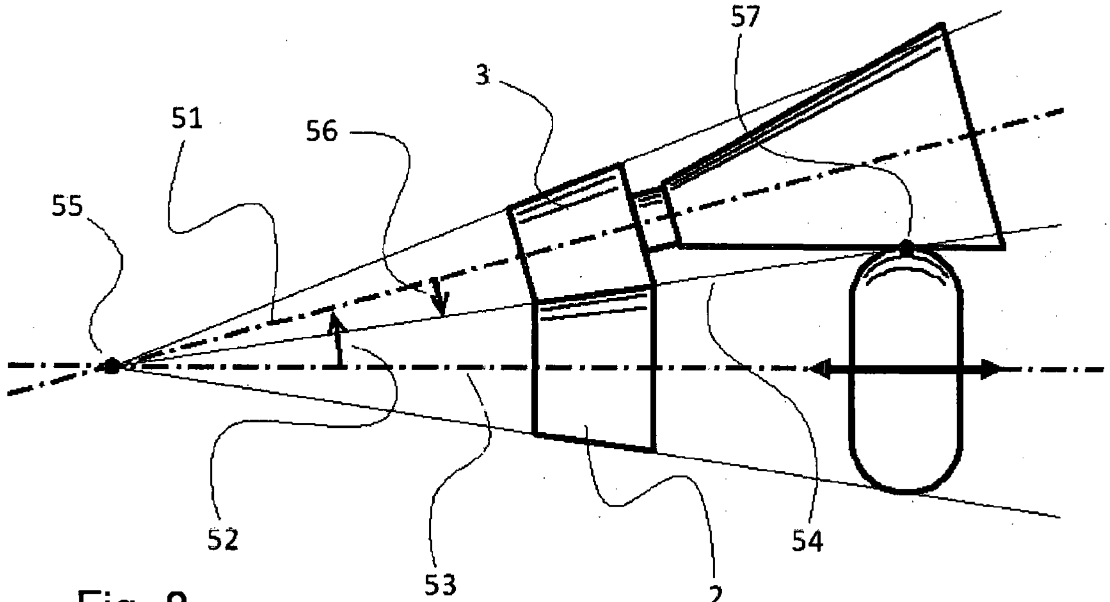


Fig. 8

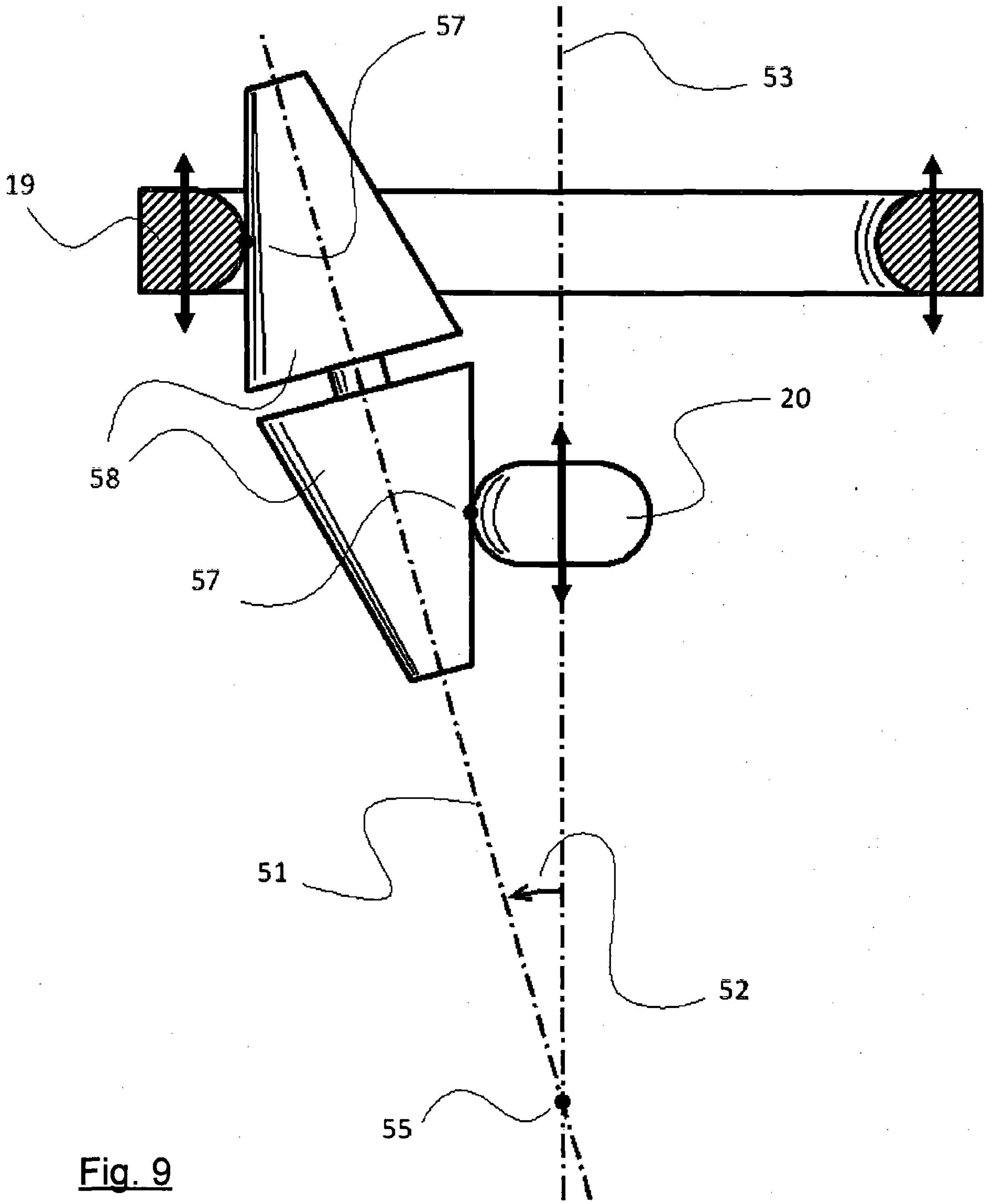


Fig. 9

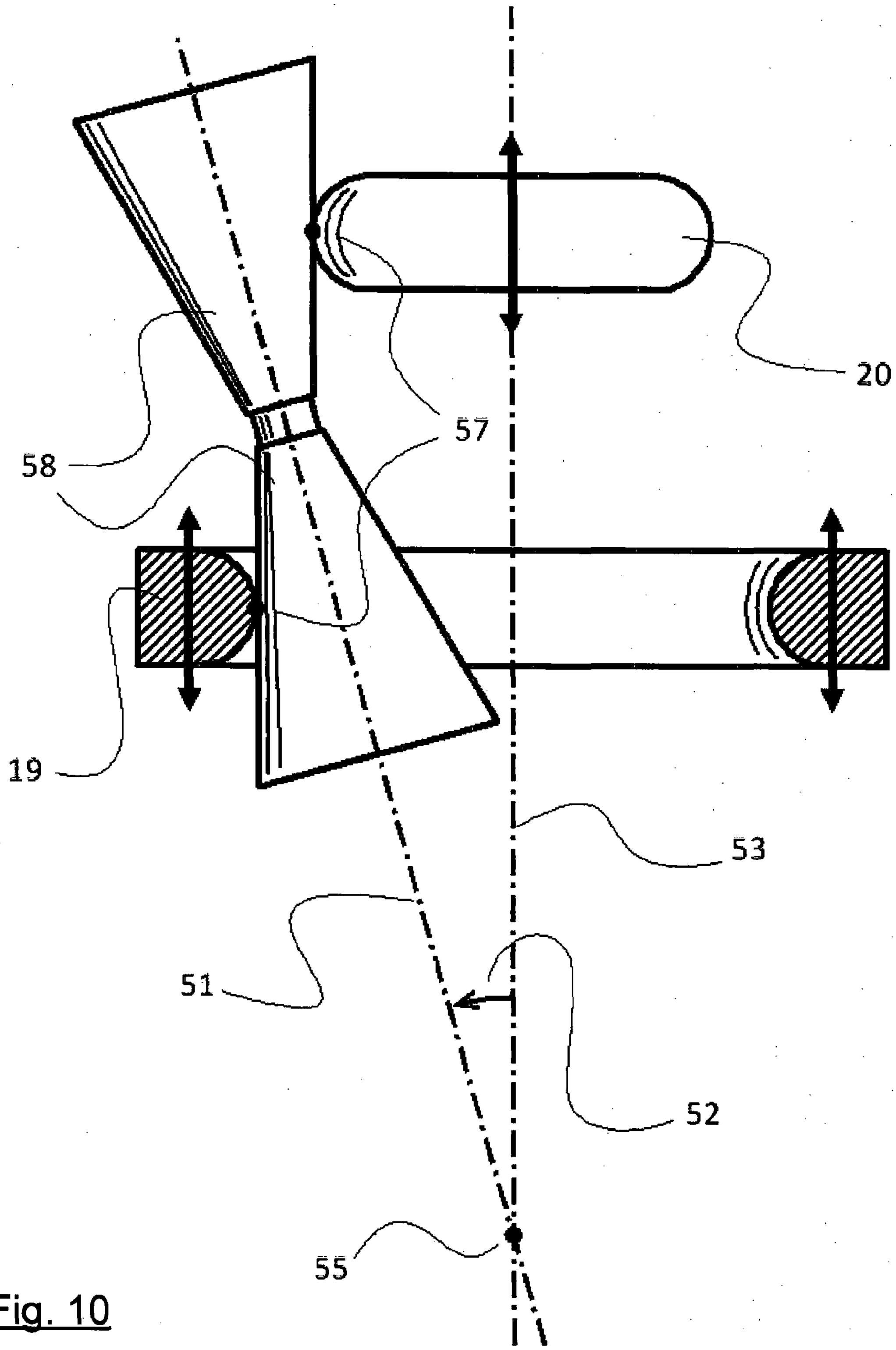


Fig. 10

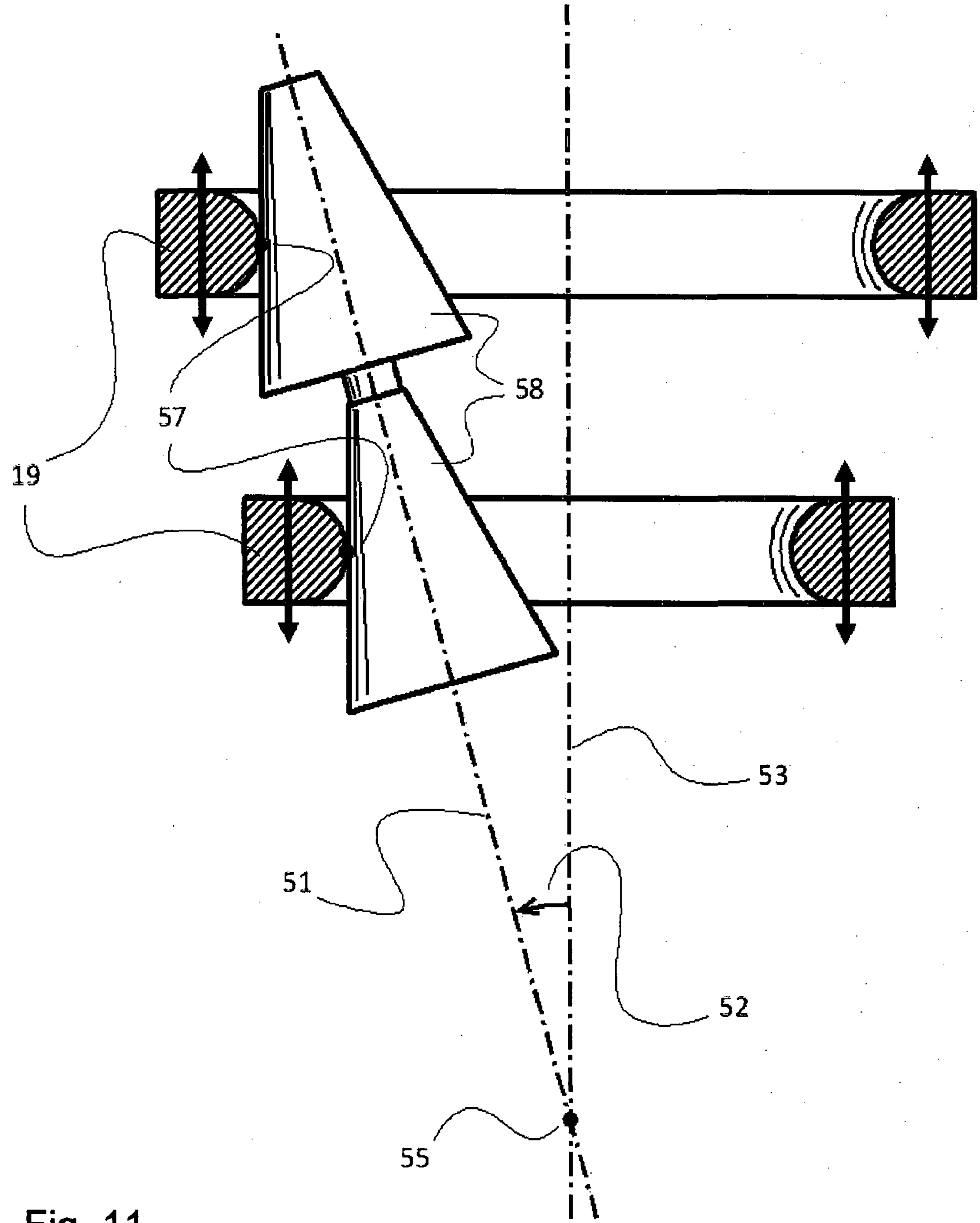


Fig. 11

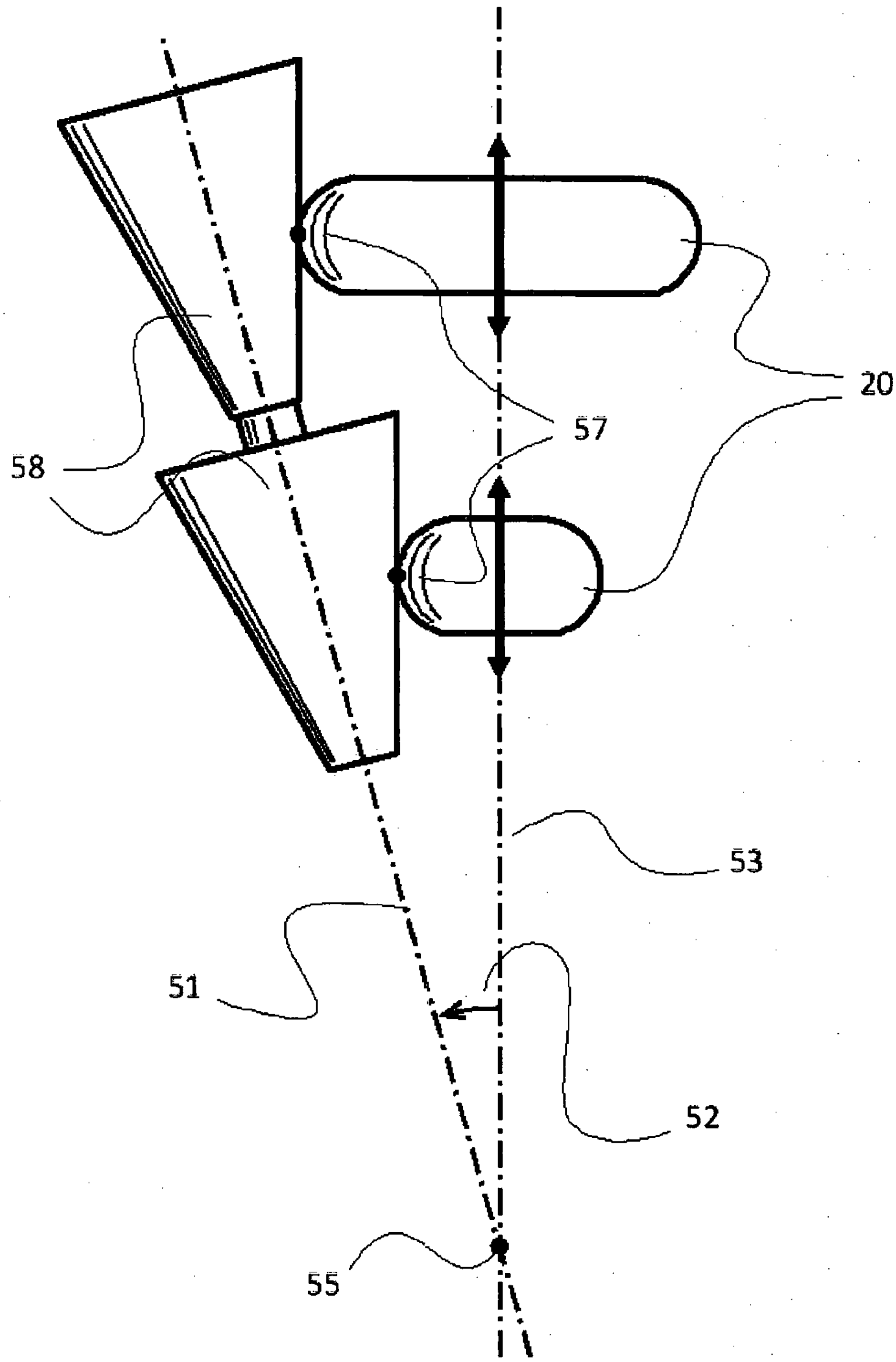


Fig. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2013/000242

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60K6/10 B60K6/445 B60K6/543 F16H15/52
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)
B60K F16H

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2011 056985 A (ISUZU MOTORS LTD) 24 March 2011 (2011-03-24)	1,9,10, 12,15, 16,18,19
Y	figure 1	17
X	EP 1 953 420 A1 (MIKUNI KOGYO KK [JP]) 6 August 2008 (2008-08-06) figures 1,2	1,9-11, 15,16, 18,19
X	US 2 403 627 A (BADE ALFRED G) 9 July 1946 (1946-07-09) figure 1	1,9,10, 13-15
X	JP S58 124855 A (TOMA KOUSHI) 25 July 1983 (1983-07-25) figures 1,3	1-8,10, 11

-/--

[X] Further documents are listed in the continuation of Box C.

[X] 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

"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
26 August 2013	11/09/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Belz, Thomas

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2013/000242

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.: 21-23
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:
see FURTHER INFORMATION sheet PCT/ISA/210

3. ☐ Claims Nos.:
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 an 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.

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2013/000242

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2010 270796 A (TOYOTA MOTOR CORP) 2 December 2010 (2010-12-02) abstract; figures 1, 2a -----	17
A	WO 2011/141646 A1 (ZANATTA PAULINE [FR]; BERGENTHAL AUDREY [FR]) 17 November 2011 (2011-11-17) abstract; figure 1 -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2013/000242

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2011056985 A	24-03-2011	NONE	
EP 1953420 A1	06-08-2008	CN 101283201 A	08-10-2008
		EP 1953420 A1	06-08-2008
		JP 5028264 B2	19-09-2012
		US 2008167154 A1	10-07-2008
		WO 2007029564 A1	15-03-2007
US 2403627 A	09-07-1946	NONE	
JP S58124855 A	25-07-1983	NONE	
JP 2010270796 A	02-12-2010	NONE	
WO 2011141646 A1	17-11-2011	EP 2568835 A1	20-03-2013
		FR 2959913 A1	18-11-2011
		WO 2011141646 A1	17-11-2011

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 21-23

Claims 21-23 are not considered to be clear (Art.6 PCT), since they do not define the matter for which protection is sought in terms of the technical features of the invention (Rule 6.3(a) PCT, but instead rely on references to the description and drawings (Rule 6.2(a) PCT).
This
deficiency is to such an extend that no meaningful search of the subject-matter of claims 21-23 is possible.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.