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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 December 2007 (06.12.2007)

PCT

(10) International Publication Number
WO 2007/138353 A2

(51) International Patent Classification:
B60K 6/10 (2006.01) *B60K 6/48* (2007.10)
B60K 6/30 (2007.10)

(21) International Application Number: PCT/GB2007/050297

(22) International Filing Date: 25 May 2007 (25.05.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0610369.1 25 May 2006 (25.05.2006) GB

(71) Applicant (*for all designated States except US*): **KESTREL POWERTRAINS LTD** [GB/GB]; 91 Langham Road, Blackburn Lancashire BB1 8DP (GB).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **SMITH, Martin** [GB/GB]; 91 Langham Road, Blackburn Lancashire BB1 8DP (GB). **PIRAULT, Jean-Pierre** [GB/GB]; 30 Lesser FoxHoles, Shorehan-By-Bea Sussex BN43 5NT (GB).

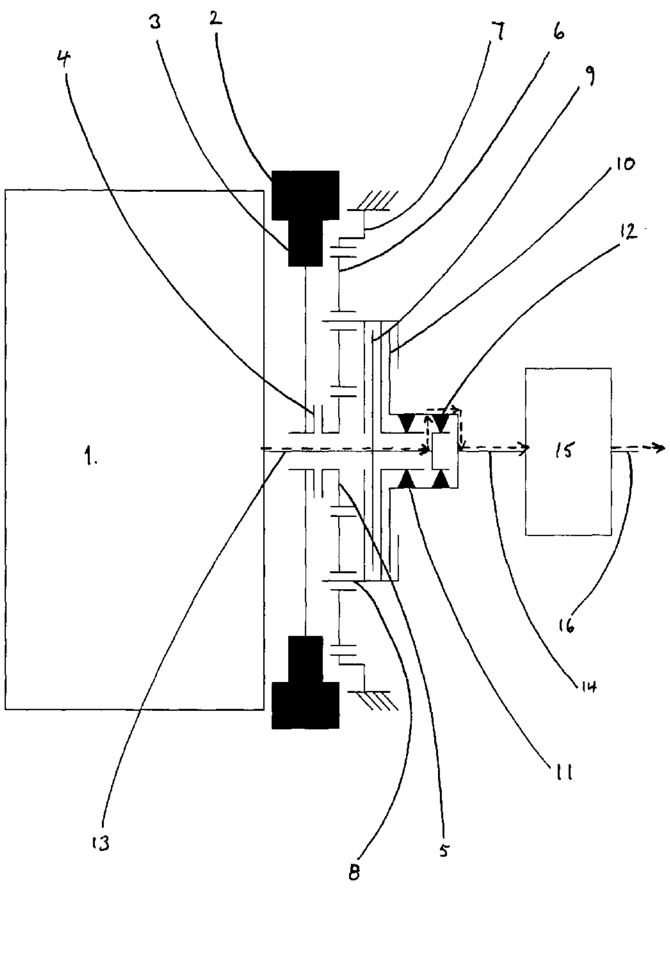
(74) Agent: **BINGHAM, IAN**; IP Asset LLP, 4th Floor, 33 Cavendish SQ, London Greater London W1G 0PW (GB).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, 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, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: REGENERATIVE BREAKING SYSTEM



(57) Abstract: A power transmission system that comprises a prime mover (1), a flywheel (2) and an epicyclic gear set with clutches (4, 9, 10 and 12) by which either the prime mover or the flywheel can be connected co-axially to the input of an infinitely variable transmission (15). The prime mover (1) may be an internal or external combustion engine. The flywheel system may comprise at least one flywheel, and optionally an electrical machine, and optionally a second flywheel which is arranged to rotate in opposite direction to the first flywheel. The transmission may be fitted with the various auxiliaries that are frequently used in vehicles and these auxiliaries may be driven by a shaft from the transmission, even with the vehicle at rest, and with the prime mover stopped. The electrical machine may also be independent of the flywheel, attached and connected to the transmission and auxiliaries via a clutch, and operated by a control system. The flywheel structure may be optionally metallic or composite.

WO 2007/138353 A2

Declarations under Rule 4.17:

- *as to the identity of the inventor (Rule 4.17(i))*
- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*
- *of inventorship (Rule 4.17(iv))*

Published:

- *without international search report and to be republished upon receipt of that report*
- *with information concerning incorporation by reference of missing parts and/or elements*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

REGENERATIVE BRAKING SYSTEM

Field of the invention

The present invention relates to a regenerative braking system for vehicles and the use of flywheels for energy storage.

Background

The energy efficiency of vehicles that operate on duty cycles involving frequent acceleration and deceleration can be improved by capturing and storing vehicle kinetic energy that would otherwise be wasted in the brakes. The energy can be reused to assist subsequent accelerations or other positive power demands in place of power input from the engine or other prime mover (a prime mover being a power producing device such as an engine or an electric motor). Flywheels are frequently used to absorb kinetic energy by increasing the rotational speed of the flywheel, and to release this stored energy for power modes by reducing the speed of the flywheel. It is also known that epicyclic gear systems can be used to control the flow of energy to and from the flywheel. The invention described below provides improved means of using an epicyclic gear train in conjunction with a flywheel and directing the power supply between the flywheel and the wheels or tracks of the vehicle.

Prior Art

Patent number US 4,519,485 discloses a vehicle driveline which includes a continuously variable transmission (CVT), an engine for driving the transmission and a flywheel for driving the transmission which is itself driven by the transmission to brake the vehicle thereby storing vehicle kinetic energy and then driving the transmission when the engine is not driving the transmission. The flywheel is mounted remote from the CVT, not coaxial with it or the engine, and connected to the CVT via spur or bevel gears and clutches.

NL-C-1023686 discloses a system in which an epicyclic gear set receives input torque from an engine or from a flywheel, the output being fed into a CVT and an output shaft.

Patent application number US4471668 discloses the drive system of a vehicle in which a flywheel is connected, via clutches, either to the engine or an element of the epicyclic gear set. The output from the epicyclic gear set is connected to a pair of hydrostatic units giving a continuously variable gear ratio between the engine or flywheel input and the output to the driven shaft. However, the mechanical layouts disclosed are relatively complex, a principle characteristic being that there are outputs from the epicyclic gear set going both to the continuously variable transmission system (shown in the form of hydrostatic units) and directly to the propeller shaft.

Patent application number US5603671 discloses the drive system of a vehicle in which a flywheel is connected to one element of a first epicyclic gear set and a prime mover shaft is connected to the same element of the first epicyclic gear set. This system is also relatively complex and is characterised in that the output from first epicyclic gear set is selectively connected either to the propeller shaft or to a second epicyclic gear set.

Patent application number WO2004/000595 discloses the drive system of a vehicle in which a motor is connected to an element of an epicyclic gear set and a flywheel is connected to another element of the epicyclic gear set via a clutch. The output from the epicyclic gear set is connected, via a clutch, directly to the propeller shaft. Moving away from rest must be accomplished by slipping that clutch, inevitably creating significant energy loss. A further characteristic of this system is that drive by flywheel only is not possible.

In the system disclosed by Greenwood C191/86 published by the Institute of Mechanical Engineers 1986, an epicyclic gear train is arranged to receive the individual outputs of the flywheel and the motor.

The system is a closed three-shaft system with no IVT. In order to control and restrict the torque delivered to the output during phases of acceleration and deceleration, excess power available in the output must be directed to the flywheel or indeed back to prime mover. Moreover, in such a system all power flows occur via the epicylic, which must be capable of transmitting the entire torque output by flywheel and/or engine and must also be capable of withstanding the accommodating increased loads to which it is subjected during a re-alignment of energy flow. In order to meet the high demands imposed upon it, the epicyclic requires robust components to withstand such loads - inevitably the epicyclic unit will be bulkier and heavier.

It is therefore an object of the current invention to overcome the deficiencies and shortcomings arising in prior art systems.

The present invention provides a simplified layout, allowing for engine and flywheel drive capability and flywheel only drive capability and having a single output from the epicyclic gear set to a transmission which is of the infinitely variable type.

An Infinitely Variable Transmission (IVT) is defined as a transmission in which the output shaft can be at rest (i.e. zero rotational speed) with all the necessary clutches engaged for power transmission to or from the prime mover while the input shaft is rotating at any speed appropriate to the prime mover. Transmission ratio, defined as input speed divided by output speed, is then infinite. Apart from an infinite drive ratio capability, the IVT enables a reverse ratio capability without a separate gear. A mechanical IVT is one in which the transmission ratio is varied by changes to the kinematic geometry of the load path between the torque input and output; the mechanical IVT uses neither fluid pressure nor electrical power as its principal means of ratio change. However, fluid pressure or electrical power may be used in the control system of the mechanical IVT.

Summary of the invention

According to the invention a power transmission system is provided comprising at least one flywheel, a prime mover shaft, and an epicyclic gear set having three elements, wherein the at least one flywheel and the prime mover shaft, are respectively connectable to two of the elements of the epicyclic gear set via at least one clutch one of the said two elements is connectable to the input of an infinitely variable transmission, via at least one clutch, the at least one flywheel, the prime mover shaft and the infinitely variable transmission are coaxial.

According to a further aspect of the invention a method of transmitting power in a transmission system is provided comprising at least one flywheel, a prime mover shaft, an epicyclic gear set having three elements and a combined electrical motor/generator/storage means, the at least one flywheel and the prime mover shaft being respectively connectable to two of the elements, by means of at least one clutch, one of the said two elements and the prime mover being connectable by means of at least one clutch to the input shaft of an infinitely variable transmission, the at least one flywheel, the prime mover shaft and the infinitely variable transmission being coaxial, the method step comprising closing the at least one clutch to connect the prime mover to the transmission

This invention differs from prior art in that none of the elements of the epicyclic gear set in the invention is connected to the output side of the IVT. Advantageously, the torques applied to the epicyclic elements are substantially smaller than the epicyclics in the prior art, where at least some of the output of the epicyclic directly feeds into the output of the vehicle. The epicylic must be capable of transmitting the entire torque output by flywheel and/or engine and must also be capable of withstanding the accommodating increased loads to which it is subjected during a re-alignment of energy flow. In the invention, on the other hand, the epicylic is connectable only to the input of the IVT ie none of the output of the epicyclic set connects to the output of the vehicle, meaning that the torque loads on the epicyclic, which flow into/from the IVT are correspondingly lower.

In addition, advantageously, the flywheel is arranged to be coaxial with the engine and IVT.

This invention is described, with various embodiments, in the following figures and text.

In one embodiment the infinitely variable transmission may be of the mechanical type. Power may be transmitted by the prime mover shaft, is routed through the infinitely variable transmission.

In one embodiment the system advantageously comprises 2 flywheels and the flywheels may rotate in opposite directions to each other.

In one embodiment the sun gear of an epicyclic gear is rigidly attached to a first flywheel,

In one embodiment at least one of the at least one flywheels may be advantageously made of at least one composite material, at least one pure material or a combination of both. The at least one of the at least one flywheels may also be made of at least one metal. The flywheel system may incorporate at least one electrical machine, which is a motor or a dynamo or a combined motor-dynamo.

The prime mover shaft is connected or connectable to a prime mover, which may be any one of the following selection: an internal combustion engine, spark ignition type, compression ignition type, 2-mode combustion system type, external combustion type, compressor turbine engine type, Sterling type or any other type of engine.

The at least one flywheel may be connected via a clutch to the sun gear of the epicyclic gear set.

In one embodiment the annulus of the epicyclic gear set is fixed, ("grounded" or "earthed").

The planet gears of the epicyclic gear set may be advantageously connectable to the prime mover shaft and selectively connected to the transmission. The planet carrier is connected via at least one clutch to the prime mover.

The clutches may be selected from a list comprising the wet plate type, the one-way type or any other type of clutch.

In one embodiment the planet carrier may be advantageously connectable via at least 2 clutches to the transmission and the clutch may be the wet plate type, one-way type or any other type of clutch.

The prime mover shaft may be connectable to the transmission via at least one clutch. In one embodiment the at least one clutch may be at least one dry pressure plate clutch.

In one embodiment each of the at least one clutch is selected from a dog clutch or a cone clutch

The system may comprise electrical control means for electrically controlling each of the at least one clutch

The system may also comprise at least one auxiliary means driven from the IVT transmission input shaft, said auxiliary means being selected from a list comprising at least one of each of the following auxiliary systems: an air compressor pump, an air vacuum pump, an air conditioning compressor, an electrical generator, a coolant pump, a hydraulic pump or any other auxiliary means.

At least one auxiliary means may advantageously be mounted on the IVT transmission, said auxiliary means being selected from a list comprising at least one of the each of the following auxiliary systems: an air compressor pump, an air vacuum pump, an air conditioning compressor, an electrical generator, a coolant pump, a hydraulic pump or any other auxiliary means

In one embodiment the system may comprise auxiliaries driven by pulleys engaging with a common belt which is driven by a pulley on a rotating input shaft of the IVT. The auxiliaries may be driven by pulleys engaging with a common belt which is driven by a pulley on the output shaft of the power transmission system.

In an embodiment of the invention the prime mover shaft is advantageously connectable via a one-way clutch to the input shaft of the transmission. In a further embodiment the flywheel system is connectable via a flywheel disconnect clutch to a sun gear. The epicyclic gear set may comprise an epicyclic sun gear connected to the epicyclic planet carrier member via the epicyclic planet gear.

The planet gear of the epicyclic may be advantageously connectable to the sun gear, the planetary gear carrier and the annulus gear and is connectable via a one-way clutch to the transmission shaft. In an embodiment the transmission shaft may be connectable to the planet carrier via a flywheel charging clutch and the flywheel disconnect clutch to the flywheel system

The transmission shaft may be connectable via the flywheel charging clutch and the flywheel top-up clutch to the prime mover shaft. The prime mover shaft is connectable via the flywheel top-up clutch to the planet carrier and via the flywheel disconnect clutch to the flywheel system

In a further embodiment of system the IVT is coupled via a first pinion and second pinion to the prime mover and the IVT drives a first track or wheel set, and a further comprises a second arrangement comprising a second IVT, said second arrangement in which the second IVT is coupled via the first pinion and a third pinion to the prime mover, wherein the second IVT drives a second track or wheel set.

The method described earlier may comprise the steps of disconnecting the prime mover from the transmission using the at least one clutch, connecting the at least one flywheel to the epicyclic using the at least one clutch, connecting the at least one flywheel to the transmission using the at least one clutch

The method may also advantageously comprise the steps of actuating the at least one clutch to disconnect the prime mover from the transmission, actuating the at least one clutch to connect the at least one flywheel to the planetary gear of the epicyclic gear set, actuating the electrical means to apply a torque to the flywheel which is transmitted to the epicyclic gear set, actuating the at least one output clutch to connect the epicylic set to the input shaft of the IVT and to drive it, if the speed of the clutch, when actuated, exceeds that of the input shaft of the IVT

The method may comprise the steps of: receiving an instruction to retard, actuating the at least one clutch to connect the epicyclic set to the input shaft of the IVT, when the said retarding instruction is received, actuating the at least one clutch to connect the at least one flywheel to the epicyclic and to drive the flywheel

The method may comprise the steps of actuating the electrical means to generate electrical energy derived from the rotating flywheel and to store the said electrical energy

The method may comprise the steps of: receiving an instruction to retard, actuating the at least one clutch to connect the epicyclic set to the input shaft of the IVT, if the said retarding instruction is received, monitoring flywheel speed and electrical energy, identifying if a maximum flywheel speed has been reached and maximum electrical energy has been reached, actuating the at least one clutch to disconnect the at least one flywheel from the epicyclic if the said maxima speed have been reached, actuating another of the at least one clutch to connect the epicyclic gear set to the prime mover shaft and to drive the prime mover shaft to achieve engine braking

The method may comprise the steps of: monitoring flywheel speed and identifying if a minimum speed has been reached, actuating the at least one clutch (4) to connect the at least one flywheel to the epicyclic, actuating another of the at least one clutch to connect the prime mover shaft to the epicyclic gear set and to drive the flywheel.

The method may comprise the steps of: monitoring flywheel speed, and identifying if it is above the referred engine idling speed, actuating the at least one clutch to connect the at least one flywheel to the epicyclic, actuating another of the at least one clutch to connect the prime mover shaft to the epicyclic gear set and to accelerate the engine

It is also foreseen that the apparatus and method herein described can be operated by a suitably programmed computer which forms part of the apparatus. The invention also provides a computer program product comprising a readable storage medium for storing instructions for implementing the method herein described on the apparatus herein described

Brief Description of Figures

Figure 1 shows a side elevation of a first embodiment of the proposed power transmission system in a first operating mode.

Figure 2 shows the system of Fig.1 in a second operating mode.

Figure 3 shows the system of Fig.1 in a third operating mode.

Figure 4 shows the system of Fig.1 in a fourth operating mode.

Figure 5 shows the system of Fig.1 in a fifth operating mode.

Figure 6 shows the system of Fig.1 in a sixth operating mode.

Figure 7 shows the system of Fig.1 in a seventh operating mode

Figure 8 shows the system of Fig.1 in an eighth operating mode.

Figure 9 shows the system with auxiliaries mounted and driven from the output shaft
of the power transmission system.

Figure 10 shows a tracked vehicle application of the proposed invention.

Detailed Description of the Preferred Embodiments

The following passage explains the passage in reference to Figures 1-8. The direction of power flow is indicated by the chain dotted line.

With reference to Fig.1, the power transmission system comprises a prime mover (1), preferably an internal or external combustion engine, that is connected to at least one infinitely variable transmission (15) via an epicyclic gear set (5, 6, 7 & 8) and clutches (9, 10, 11, 12) and via a clutch (4) to a flywheel system (2), the transmission being connected to an external load via a driveline, or propeller shaft (16). The epicyclic gear set comprises the annulus gear (7), which is, preferably, fixed, ie does not rotate relative to the engine or any part in this system, planet gears (6) mounted on the planet carrier (8) and connected to the flywheel top-up clutch (9) and the flywheel charging clutch (10), and a sun gear (5) which connects via clutch (4) to the flywheel system (2). The planet gears of at least one epicyclic gear set are therefore connected to the prime mover and transmission.

The transmission may be connected via a transmission shaft (14) to a one way clutch (11) to the flywheel charging clutch (10), and also connects via the one way clutch (12) to the prime mover via shaft (13). The flywheel system may comprise at least one flywheel, and optionally an electrical machine (3), and optionally a second flywheel (not shown) which is, preferably, arranged to rotate in opposite direction to the first flywheel. The transmission may be fitted with various auxiliaries that are frequently used in vehicles, such as power assisted steering pump, power assisted brake pump, air conditioning pumps, vehicle suspension load levelling pumps, air pumps and compressors, such that these auxiliaries may be driven independently of the prime mover. The electrical machine may also be independent of the flywheel and attached and connected to the transmission and auxiliaries via a clutch. The electrical machine may be connected to a battery pack via power electronics. The various elements of the previously described electrical system would be controlled by an electronic control unit.

With reference to Fig.1, the planet carrier may be connected via at least two clutches to the prime mover, with at least one of these clutches preferably being of the wet plate type, with at least a single one way clutch which is preferably of the sprag type.

The planet carrier may be connected via at least two clutches to the transmission, in which at least one clutch is preferably of the wet plate type, with at least a single one way clutch which is preferably of the sprag type.

The flywheel system may comprise at least one flywheel which may be made of ferrous material such as steel, fibre composite, such glass fibres, carbon fibres which may include epoxy bonding, or metal matrix composites, such as alumina reinforced aluminium, or titanium diboride reinforced steel. In one embodiment of the alumina reinforced aluminium, the alumina fibres may be arranged in the form of a structured matrix, which in one case may have fibres arranged in an orthogonal pattern to each other or one in which the fibres are orthogonally woven.

With reference to the two-flywheel arrangement, a spur or epicyclic gear set may be used to generate the contra-rotation of the flywheels. For the spur gear arrangement, the spur gear may be rigidly fixed to a first flywheel, whilst for the epicyclic arrangement, the sun gear of an epicyclic gear set is rigidly attached to a first flywheel,

The prime movers may be compression ignition internal combustion engines, spark ignition internal combustion engines or mixed mode internal combustion engines, ie compression or spark ignition internal combustion engines operating either in their normal mode or in homogenous charge compression ignition mode. In another embodiment, the internal combustion engine may switch between 2 modes of combustion, i.e either compression ignition and homogenous charge compression ignition modes, or spark ignition and homogenous charge compression ignition modes. Any suitable prime mover could be used.

The prime mover may be an external combustion engine of a compressor turbine engine type or of a Sterling engine type.

In Figure 1, the power transmission system is arranged such that the prime mover 1 drives via the drive shaft 13. When the shaft (13) speed exceeds that of the transmission shaft (14), due to prime mover positive torque transmission, the one way clutch 12 transmits the torque from the engine shaft 13 to the transmission shaft 14, and then into the transmission 15. If the torque from the engine is reduced so that the speed of the engine shaft 13 falls below the speed of the transmission drive shaft 14, the one way clutch 12 will over run, ie freewheel.

With reference to Fig.2, the Flywheel (2) drives the epicyclic sun gear (5) through the flywheel disconnect clutch (4). The epicyclic sun gear (5) drives the epicyclic planet carrier member (8) via the epicyclic planet gears (6). When the speed of the epicyclic planet carrier member (8) exceeds that of the transmission shaft (14), the one way clutch (11) transmits the torque from the epicyclic planet carrier member (8) to the transmission shaft (14), and thence into the transmission (15) as in Figure 2.

If the speed of the epicyclic planet carrier member (8) drops below that of the transmission shaft (14), the one way clutch (11) will over run freely.

It can be seen that a significant difference between the system described here and patent application number US4471668 A is that in the system described here all of the power transmitted by the prime mover shaft (13), apart from internal losses, is routed through the infinitely variable transmission (15). That power is transmitted via the epicyclic gear set and some of it may be routed, temporarily, through the flywheel (2) but, ultimately, all of the available power enters or leaves the system through the IVT (15).

With reference to Fig.3, the electric motor/generator rotating member (3) drives the epicyclic sun gear (5) through the flywheel disconnect clutch (4). The epicyclic sun gear (5) drives the epicyclic planet carrier member (8) via the epicyclic planet gears (6). When the speed of the epicyclic planet carrier member (8) exceeds that of the transmission shaft (14), the one way clutch (11) transmits the torque from the epicyclic planet carrier member (8) to the transmission shaft (14), and thence into the transmission (15).

If the speed of the epicyclic planet carrier member (8) drops below that of the transmission shaft (14), the one way clutch (11) will over run freely.

In response to an operator input, eg by applying the vehicles breaks, the vehicle will decelerate. The operator input is received by a control system (not shown) for controlling the operation of the clutches. With reference to Figure 4, the transmission applies a retarding torque to the vehicle propeller shaft, (16), the reaction of which generates torque on the transmission shaft (14). With the flywheel charging clutch (10) closed, the torque is transmitted via the Epicyclic planet carrier member (8), the epicyclic planet gears (6), the epicyclic sun gear (5) and the flywheel disconnect clutch (4) to the energy storage flywheel (2).

With reference to Fig.5, the transmission applies a retarding torque (as descrbed above in relation to operator input) to the vehicle propeller shaft (16), the reaction of which generates torque on the transmission shaft (14). With the flywheel charging clutch (10) closed, the torque is transmitted via the epicyclic planet carrier member (8), the epicyclic planet gears (6), the epicyclic sun gear (5) and the flywheel disconnect clutch (4) to the electric motor rotating member (3).

The electric motor rotating member (3) converts the torque applied to it into electrical power via a control system (not shown) to an electrical energy storage battery (not shown) or electrical heating elements (not shown).

With reference to Fig.6, the transmission applies a retarding torque (as descrbed above) to the vehicle propeller shaft (16), the reaction of which generates torque on the transmission shaft (14). If the energy storage flywheel (2) is at its maximum speed, and the electric motor rotating member (3) cannot transmit any more power to its electrical energy storage battery or heating elements, then the flywheel charging clutch (10), and the flywheel top-up clutch (9) are closed to transmit torque to the engine shaft (13). The flywheel disconnect clutch (4) is open so that the energy storage flywheel (2) is not affected by the speed of the engine shaft (13).

By this means, engine braking can be achieved by increasing the speed of the prime mover engine (1) until its rotating and pumping losses provide the required torque on the engine shaft (13).

With reference to Fig.7, In this mode, when the energy storage flywheel (2) reaches its minimum operating speed, the electric motor rotating member (3) provides sufficient torque to maintain that operating speed via its electrical control system (not shown).

With reference to Fig.8, when the energy storage flywheel (2) reaches its minimum operating speed, the prime mover (1) is connected to the energy storage flywheel (2) via the flywheel top-up clutch (9), the epicyclic planet carrier member (8), the epicyclic planet gears (6), the epicyclic sun gear (5) and the flywheel disconnect clutch (4).

The torque to accelerate the energy storage flywheel (2) is provided by the prime mover (1) via its own control system (not shown).

With reference to Fig.9, the auxiliaries required to maintain, for example, the vehicle steering (i.e. power steering pumps), brake systems, air conditioning and any compressed air operated equipment within the vehicle, for example pneumatically operated doors, “kneeling” suspension and braking systems, and pumps for circulating coolant for the vehicle heating system, and alternators are mounted on either the power transmission casing or the IVT and driven by a shaft of the power transmission system, or a shaft in the IVT that remains rotating at idle, driven by the flywheel energy, or by the prime mover if there is inadequate flywheel energy. In one embodiment, these auxiliaries may be driven from pulleys by a common belt that engages with a main driving pulley on the output shaft (14) from the flywheel power transmission system, with the auxiliaries mounted on the casing of the power transmission system. Fig.9 shows, as an example layout, a prime mover (1) which connects rigidly with a power transmission system (17) which is connected to an IVT (15) which has an output shaft (16). From the output shaft (not visible in Fig.9) of the power transmission system (17), there is a drive unit (18) which connects the output shaft of the power transmission casing to various auxiliaries such as an air compressor (25), a vacuum pump (19), an air conditioning pump (20), a power steering pump (21) and a generator (not shown), using either gears, or chain sprockets connected by a chain, or pulleys connected by a belt. These auxiliaries, which may either be mounted rigidly via connections (24) to the IVT (15) or to the power transmission system (17), would be connected by shafts, such as (22) which are usually part of each auxiliary, to the gears, sprockets or pulleys in the drive unit.

In another embodiment, the auxiliary drives shown in Figure 9 may be driven by a drive unit using gears meshed with the IVT input shaft (14) (not shown)

With reference to Fig.10, the prime mover (1) is coupled to a power transmission system (17). The prime mover and power transmission system may be arranged on the same side of the input shaft (14) as in Fig 1, or as shown in Figure 10, on opposite sides, dependent on the required packaging configuration. The input shaft (14) is thus driven and controlled in the same way as shown in Figure 1. The input shaft (14) to the IVT(s) may be connected to a bevel gear (31) driving simultaneously two other bevel gears (32 & 33) each of which then drives a separate IVT (27 & 28 respectively) The IVTs (27 & 28) each drive a tracked or multiple wheel set (29 & 30) with independent controls, so that torque can be applied in either direction to either track or multiple wheel set independent of the speeds thereof. Thus steering can be achieved accurately with continuous control. Also torque can be transferred from one track to the other without using brakes to control the tracks.

The previously mentioned electrical machine may be a generator or motor, or both, and may be either of an AC type, in one embodiment an induction AC type, or of a DC type, which may be in one embodiment a permanent magnet type. The permanent magnets may be of the neodymium-iron-boron type. In other DC embodiments, the rotor flux path may either be arranged to be of an axial flow or radial flow type

In summary, the previously described power modes of the power transmission system include a power transmission mode which is achieved by a one way clutch connecting the flywheel to the transmission via at least one pressure plate clutch, another power transmission mode is achieved by closing at least two pressure plate clutches attached to the planetary carrier of the epicyclic gear set, another mode being achieved by closing the pressure plate clutches attached to the planetary carrier of the epicyclic gear set and the flywheel/motor and then applying electric motor torque, another power transmission mode being achieved by closing a second pressure plate clutch attached to the planetary carrier of the epicyclic gear set and opening the flywheel disconnect clutch, another power transmission mode being achieved by closing a second pressure plate clutch attached to the planetary carrier of the epicyclic gear set, closing the flywheel disconnect clutch and using the power supplied to the motor/generator to generate electrical current to charge the vehicle battery, and another power transmission mode being achieved by closing a second pressure plate clutch attached to the planetary carrier of the epicyclic gear set, closing the flywheel disconnect clutch and transmitting power from the prime mover to accelerate the flywheel system.

Another power transmission mode is achieved by closing a second pressure plate clutch attached to the planetary carrier of the epicyclic gear set, closing the flywheel disconnect clutch and transmitting power from the flywheel to start/accelerate the prime mover, whilst another power transmission mode is achieved by closing a second pressure plate clutch attached to the planetary carrier of the epicyclic gear set and opening the flywheel disconnect clutch.

A further power transmission mode is achieved by closing a second pressure plate clutch attached to the planetary carrier of the epicyclic gear set, closing the flywheel disconnect clutch and using the power supplied to the motor/generator to generate electrical current to charge the vehicle batteries.

Another power transmission mode is achieved by closing a second pressure plate clutch attached to the planetary carrier of the epicyclic gear set, closing the flywheel disconnect clutch and transmitting power from the prime mover to accelerate the flywheel system.

Another power transmission mode is achieved by closing a second pressure plate clutch attached to the planetary carrier of the epicyclic gear set, closing the flywheel disconnect clutch and transmitting power from the flywheel to start/accelerate the prime-mover.

In the previously described power transmission system, the flywheel disconnect clutch may optionally be operated in response to electrical signals, the flywheel top-up clutch may optionally be operated in response to electrical signals and the flywheel charging clutch may optionally be operated in response to electricalsignals.

In another embodiment, the power transmission system may use dog or cone clutches.

In another embodiment, the engine and power transmission system are coupled to a split drive in which each output pinion is connected to an IVT that in turn connects to a multiple wheel set or track.

The previously described power transmission system is used with an infinitely variable transmission such as, for example, the half or full toroidal type, one using belts and chains, hydraulics or electrical shunt arrangements. These transmissions, which may themselves be under electronic control, would interface, via high speed communication links and electronic control units (ECUs), with sensors and/or actuators on the various rotating elements and clutches of the power transmission system. The power transmission ECUs would also interface, via communication links, with the ECU controlling the prime mover. Alternatively, a master ECU can be used to interface with all sensors and actuators of the prime mover and power transmission system, so that there are a reduced number of ECUs.

CLAIMS

1) A power transmission system comprising at least one flywheel (2), a prime mover shaft (13), and an epicyclic gear set (5, 6, 7, 8) having three elements,

wherein

the at least one flywheel (2) and the prime mover shaft (13), are respectively connectable to two of the elements of the epicyclic gear set (5, 6, 7, 8) via at least one clutch (4,9,10)

one of the said two elements is connectable to the input of an infinitely variable transmission (15), via at least one clutch (11,12)

the at least one flywheel (2), the prime mover shaft (13) and the infinitely variable transmission (15) are coaxial.

2) A power transmission system, as claimed in Claim 1, in which the infinitely variable transmission (15) is of the mechanical type.

3) A power transmission system, as claimed in Claim 1, in which all of the power transmitted by the prime mover shaft (13), is routed through the infinitely variable transmission (15).

4) A power transmission system, as claimed in Claim 1, comprising 2 flywheels.

5) A power transmission system, as claimed in Claim 4, in which the flywheels rotate in opposite directions to each other.

6) A power transmission system, as claimed in any previous claim, wherein the sun gear of an epicyclic gear is rigidly attached to a first flywheel,

7) A power transmission system, as claimed in any previous claim, wherein at least one of the at least one flywheels is made of at least one composite material.

8) A power transmission system, as claimed in any previous claim, wherein at least one of the at least one flywheels is made of at least one metal.

9) A power transmission system, as claimed in any previous claim, in which the flywheel system incorporates at least one electrical machine (3), which is a motor or a dynamo or a combined motor-dynamo.

10) A power transmission system, as claimed in any previous claim, in which the prime mover shaft is connected to a prime mover (1).

11) A power transmission system, as claimed in Claim 10, in which the prime mover is one of an internal combustion engine, spark ignition type, compression ignition type, 2-mode combustion system type, external combustion type, compressor turbine engine type, Sterling type.

12) A power transmission system, as claimed in any previous claim, in which at least one flywheel is connected via a clutch to the sun gear (5) of the epicyclic gear set.

13) A power transmission system, as claimed in any previous claim, in which the annulus (7) of the epicyclic gear set is fixed, ("grounded" or "earthed").

14) A power transmission system, as claimed in any previous claim, in which, the planet gears (6) of the epicyclic gear set are selectively connected to the prime mover shaft (13) and selectively connected to the transmission (7).

15) A power transmission system, as claimed in any previous claim, in which the planet carrier is connected via at least one clutch to the prime mover.

16) A power transmission system, as claimed in any claim previous claim, in which each at least one clutch is selected from the wet plate type, the one-way type

17) A power transmission system, as claimed in any previous claim, in which the planet carrier is connected via at least 2 clutches to the transmission.

18) A power transmission system, as claimed in Claim 17, in which at least one clutch is selected from the wet plate type, one-way type.

19) A power transmission system, as claimed in any previous claim, in the prime mover shaft is connectable to the transmission via at least one clutch.

20) A power transmission system as claimed in Claim 19 wherein the at least one clutch is at least one dry pressure plate clutch.

21) A power transmission system, as claimed in any previous claim wherein each of the at least one clutch is selected from a dog clutch or a cone clutch

22) A power transmission system as claimed in any previous claim further comprising electrical control means for electrically controlling each of the at least one clutch

23) A power transmission system as claimed in any previous claim further comprising at least one auxiliary means which is driven from the IVT transmission input shaft, said auxiliary means being selected from a list comprising at least one of each of the following auxiliary systems:
- an air compressor pump
- an air vacuum pump
- an air conditioning compressor
- an electrical generator
- a coolant pump
- an hydraulic pump

24) A power transmission system as claimed in any previous claim further comprising at least one auxiliary means mounted on the IVT transmission, said auxiliary means being selected from a list comprising at least one of the each of the following auxiliary systems:
- an air compressor pump
- an air vacuum pump
- an air conditioning compressor
- an electrical generator
- a coolant pump
- an hydraulic pump

25) A power transmission system as claimed in any previous claim, further comprising auxiliaries (19, 20, 21 and 25) driven by pulleys engaging with a common belt which is driven by a pulley on a rotating input shaft of the IVT.

26) A power transmission system as claimed in any previous claim, in which the auxiliaries (19, 20, 21 and 25) are driven by pulleys engaging with a common belt which is driven by a pulley on the output shaft (14) of the power transmission system

27)A power transmission system as claimed in any previous claim in which the prime mover shaft (13) is connectable via a one-way clutch (12) to the input shaft (14) of the transmission.

28)A power transmission system as claimed in any previous claim in which the flywheel system (2) is connectable via a flywheel disconnect clutch to a sun gear (5)

29)A power transmission system as claimed in any previous claim in which the epicyclic gear set comprises an epicyclic sun gear (5) connected to the epicyclic planet carrier member (8) via the epicyclic planet gear (6).

30)A power transmission system as claimed in Claim 6 in which the planet gear is connected to the sun gear, the planetary gear carrier and the annulus gear (6) and is connectable via a one-way clutch to the transmission shaft (14)

31)A power transmission system as claimed in any previous claim in which the transmission shaft (14) is connectable to the planet carrier (8) via a flywheel charging clutch (10) and the flywheel disconnect clutch (4) to the flywheel system (2)

32)A power transmission system as claimed in any previous claim in which the transmission shaft (14) is connectable via the flywheel charging clutch (10) and the flywheel top-up clutch (9) to the prime mover shaft (13)

33)A power transmission system as claimed in any previous claim in which the prime mover shaft (13) is connectable via the flywheel top-up clutch (9) to the planet carrier (8) and via the flywheel disconnect clutch (4) to the flywheel system (2)

34) A power transmission system, comprising

- a system as claimed in any previous claim wherein the IVT is coupled via a first pinion (31) and second pinion (32) to the prime mover (1) and the IVT drives a first track or wheel set (29), and
- a second arrangement comprising a second IVT, said second arrangement in which the second IVT is coupled via the first pinion (31) and a third pinion (33) to the prime mover (1), wherein the second IVT drives a second track or wheel set (30).

35) A method of transmitting power in a transmission system comprising at least one flywheel (2), a prime mover shaft (13), an epicyclic gear set (5, 6, 7, 8) having three elements and a combined electrical motor/generator/storage means,

- the at least one flywheel (2) and the prime mover shaft (13) being respectively connectable to two of the elements (5, 6, 7, 8), by means of at least one clutch (4,9,10).
- one of the said two elements and the prime mover being connectable by means of at least one clutch (11,12) to the input shaft of an infinitely variable transmission (15),
- the at least one flywheel (2), the prime mover shaft (13) and the infinitely variable transmission (15) being coaxial,

the method steps comprising

- closing the at least one clutch (12) to connect the prime mover to the transmission

36) A method of transmitting power in a transmission system as in Claim 35 further comprising the steps of:

- disconnecting the prime mover from the transmission using the at least one clutch (12)
- connecting the at least one flywheel to the epicyclic (5,6,7,8) using the at least one clutch (4)
- connecting the at least one flywheel to the transmission using the at least one clutch (11)

37) A method of transmitting power in a transmission system as in Claim 35 further comprising the steps of:

- actuating the at least one clutch (12) to disconnect the prime mover from the transmission
- actuating the at least one clutch (4) to connect the at least one flywheel to the planetary gear of the epicyclic gear set
- actuating the electrical means to apply a torque to the flywheel which is transmitted to the epicyclic gear set

- Actuating the at least one output clutch to connect the epicylic set to the input shaft of the IVT and to drive it, if the speed of the clutch (11), when actuated, exceeds that of the input shaft of the IVT

38) A method of transmitting power in a transmission system as in Claim 37 further comprising the steps of:
- Receiving an instruction to retard
- Actuating the at least one clutch (10) to connect the epicyclic set (5,6,7,8) to the input shaft of the IVT (14), when the said retarding instruction is received
- Actuating the at least one clutch (4) to connect the at least one flywheel to the epicyclic and to drive the flywheel

39) A method of transmitting power in a transmission system as in Claim 38 further comprising the steps of:
- Actuating the electrical means to generate electrical energy derived from the rotating flywheel and to store the said electrical energy

40) A method of transmitting power in a transmission system as in Claim 38 further comprising the steps of:
- Receiving an instruction to retard
- Actuating the at least one clutch (10) to connect the epicyclic set to the input shaft of the IVT, if the said retarding instruction is received
- Monitoring flywheel speed and electrical energy
- identifying if a maximum flywheel speed has been reached and maximum electrical energy has been reached
- Actuating the at least one clutch (10) to disconnect the at least one flywheel from the epicyclic (5,6,7,8) if the said maxima speed have been reached
- Actuating another of the at least one clutch (9) to connect the epicyclic gear set to the prime mover shaft and to drive the prime mover shaft to achieve engine braking

41) A method of transmitting power in a transmission system as in Claim 35 further comprising the steps of:
- Monitoring flywheel speed and identifying if a minimum speed has been reached
- Actuating the at least one clutch (4) to connect the at least one flywheel to the epicyclic
- Actuating another of the at least one clutch (9,10) to connect the prime mover shaft to the epicyclic gear set and to drive the flywheel.

42) A method of transmitting power in a transmission system as in Claim 35 further comprising the steps of:

- Monitoring flywheel speed, and identifying if it is above the referred engine idling speed
- Actuating the at least one clutch (4) to connect the at least one flywheel to the epicyclic (5,6,7,8)
- Actuating another of the at least one clutch (9,10) to connect the prime mover shaft to the epicyclic gear set and to accelerate the engine

43) A computer program product comprising a readable storage medium for storing instructions for implementing the method of Claims 35 to 42 on the apparatus of Claims 1 to 34

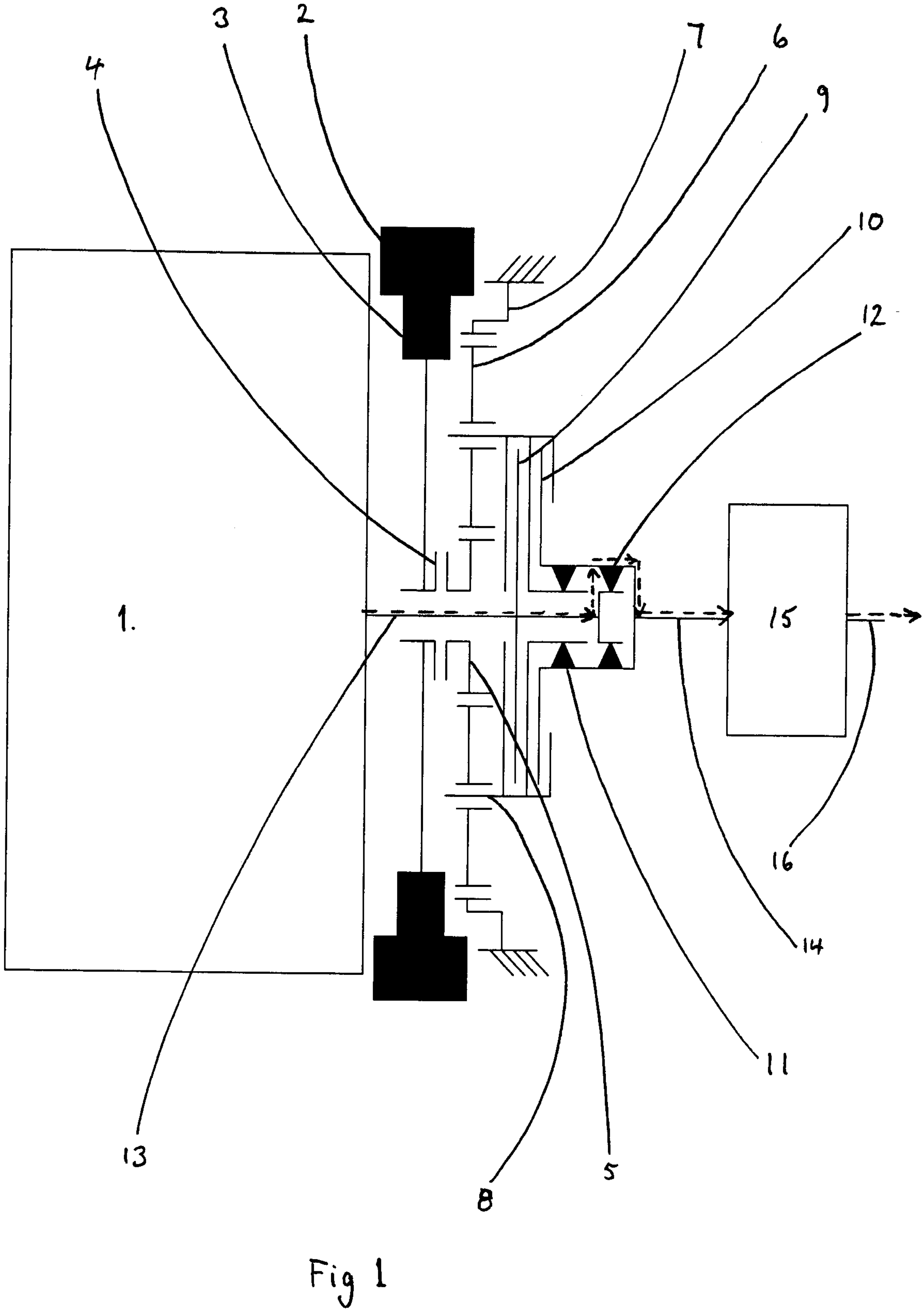


Fig 1

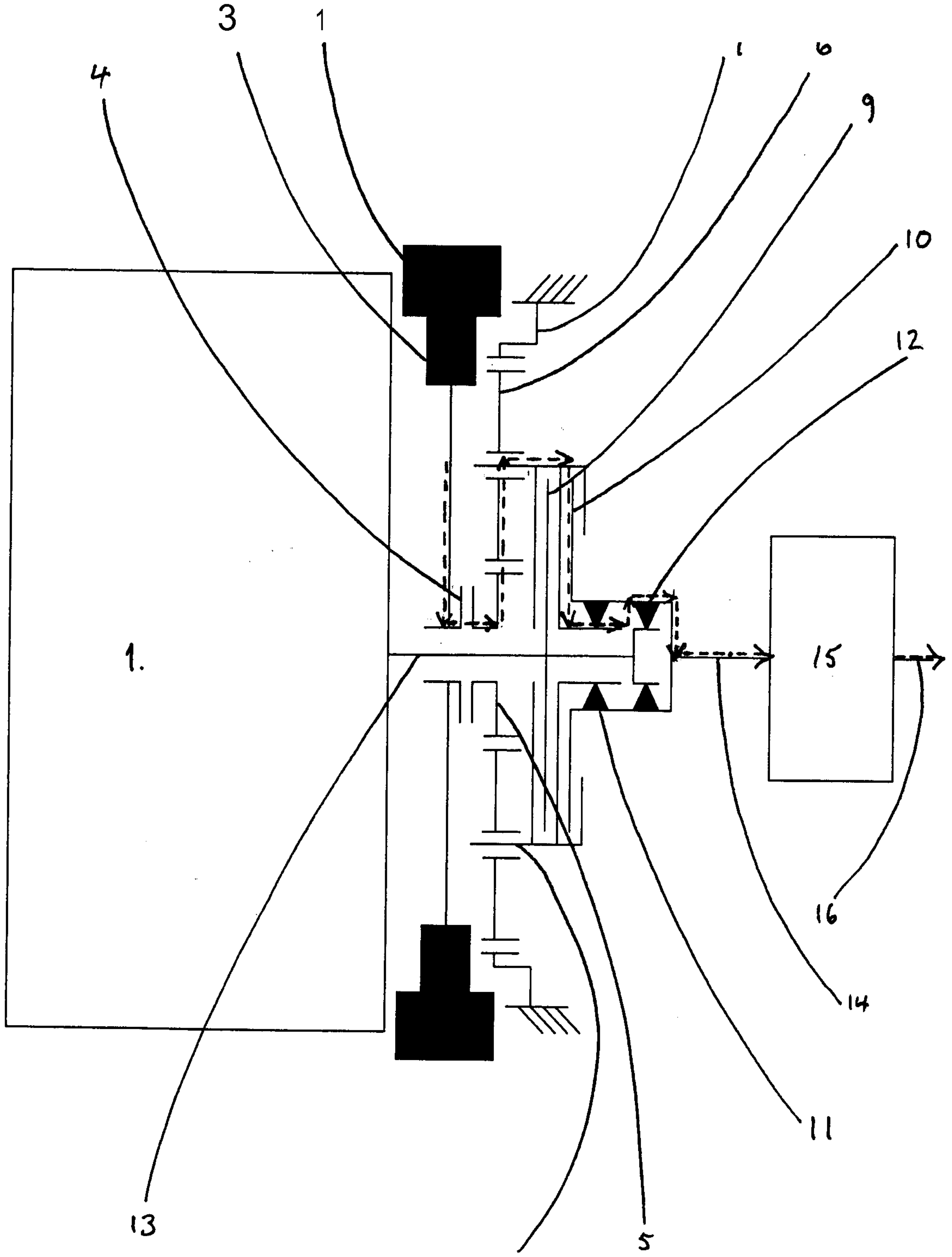


Fig 2

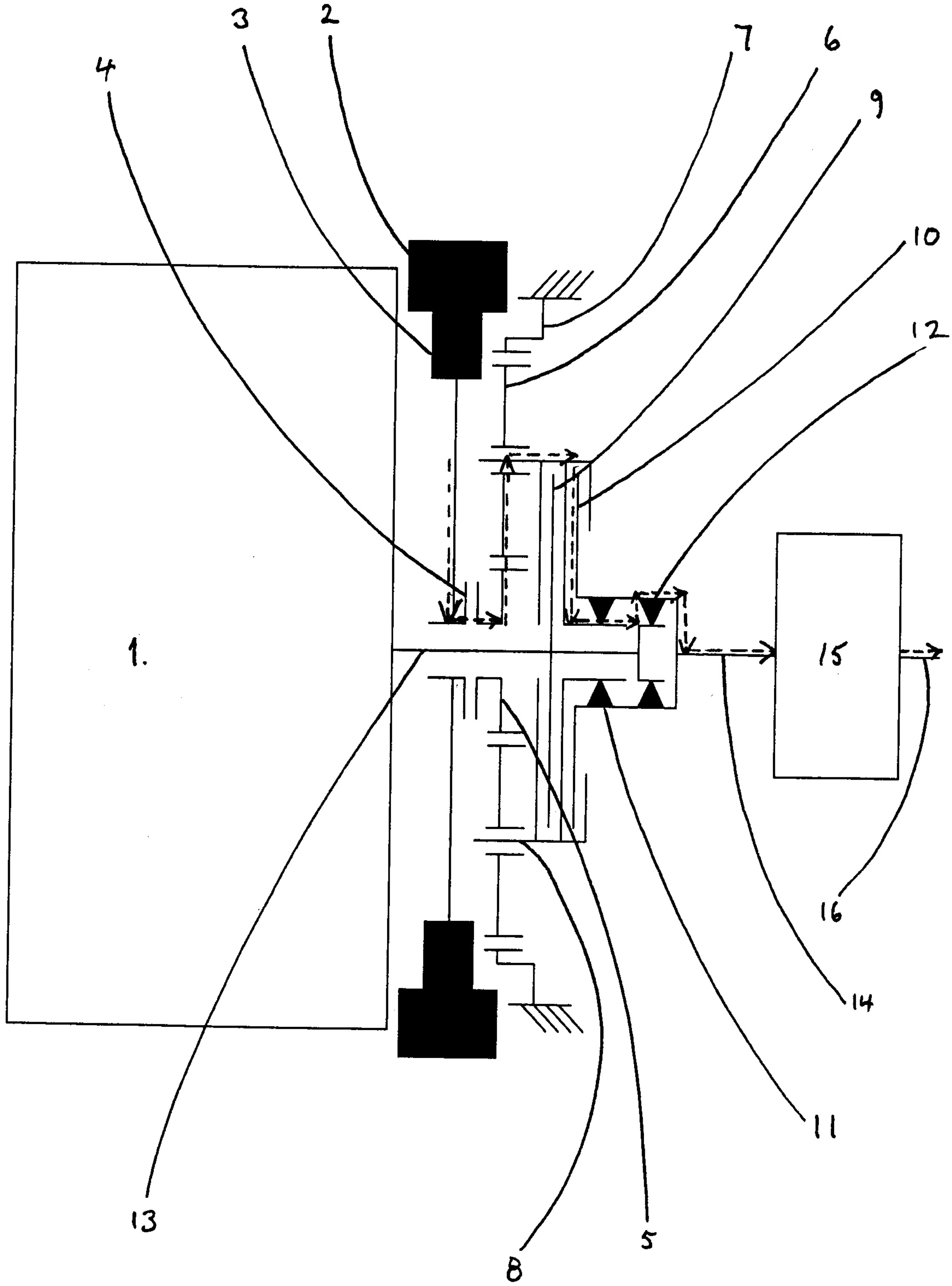


Fig 3

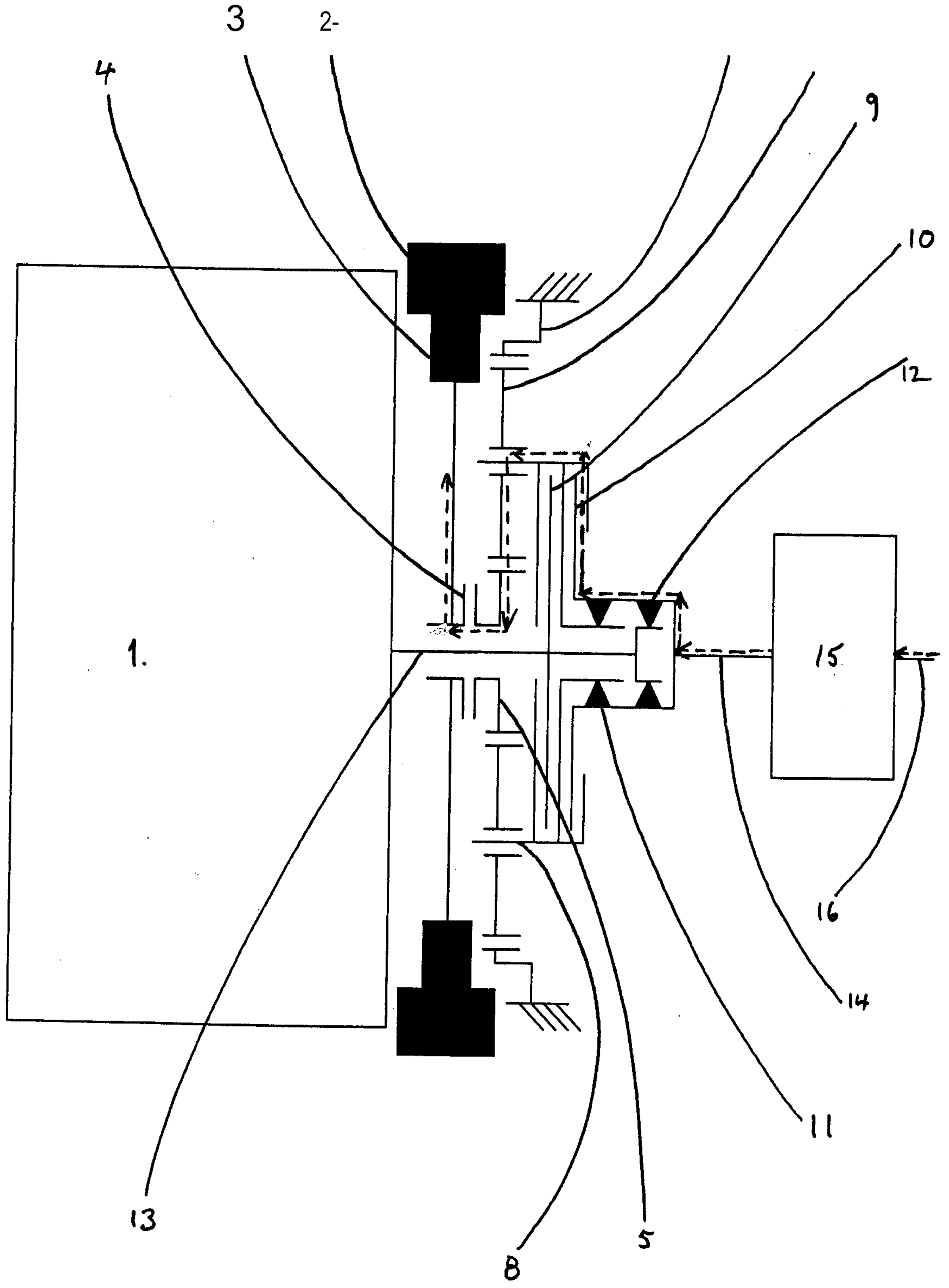


Fig 4

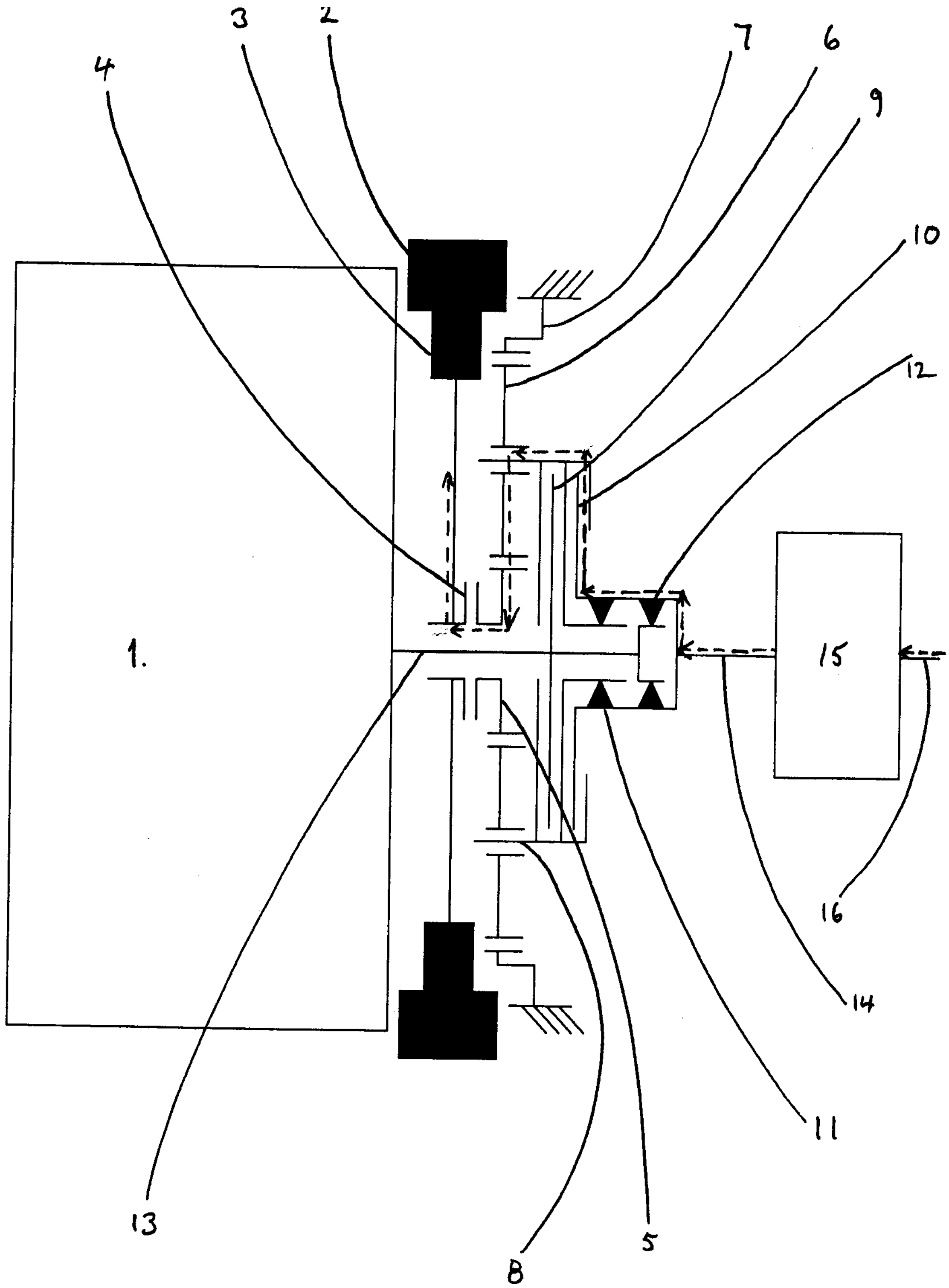


Fig 5

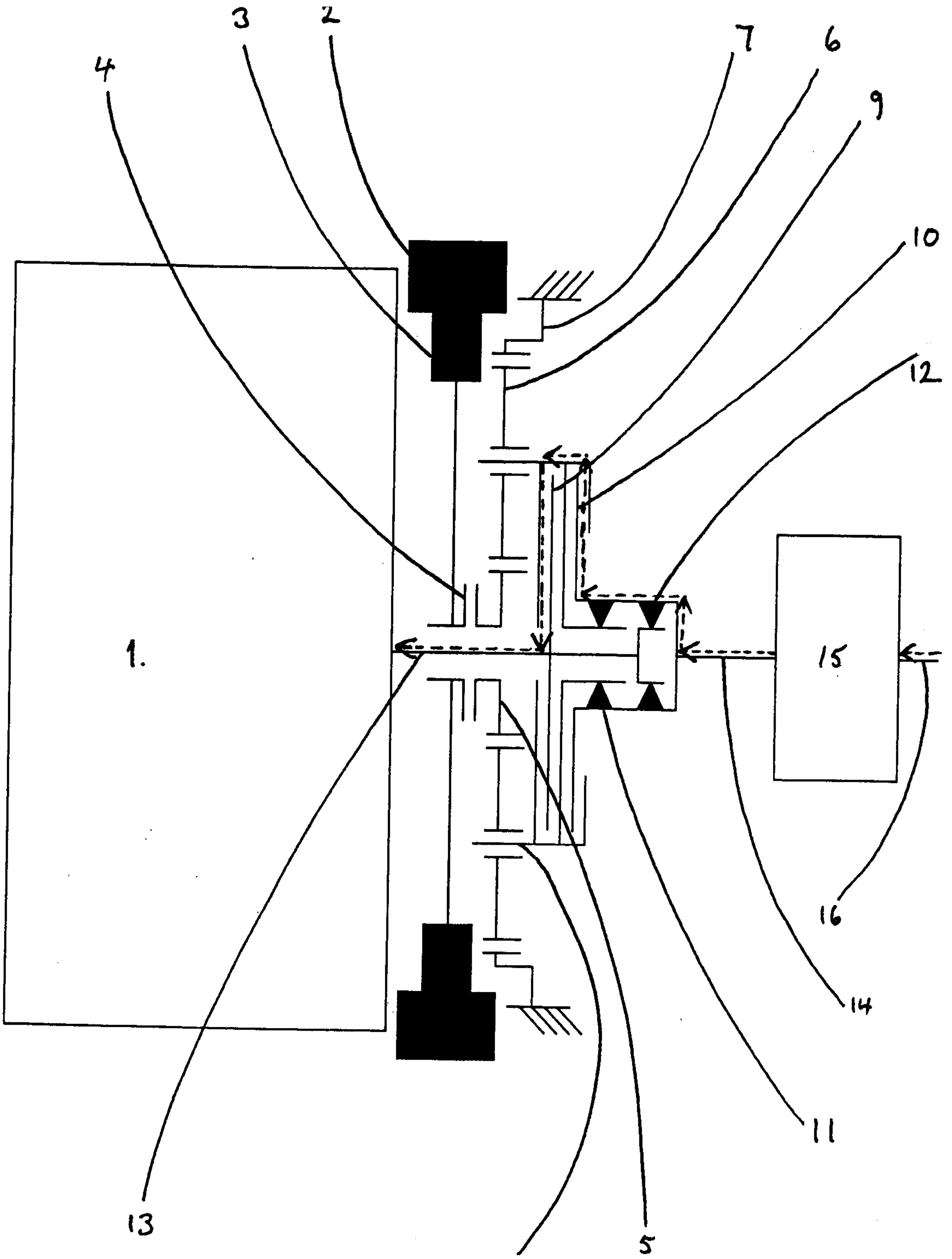


Fig 6

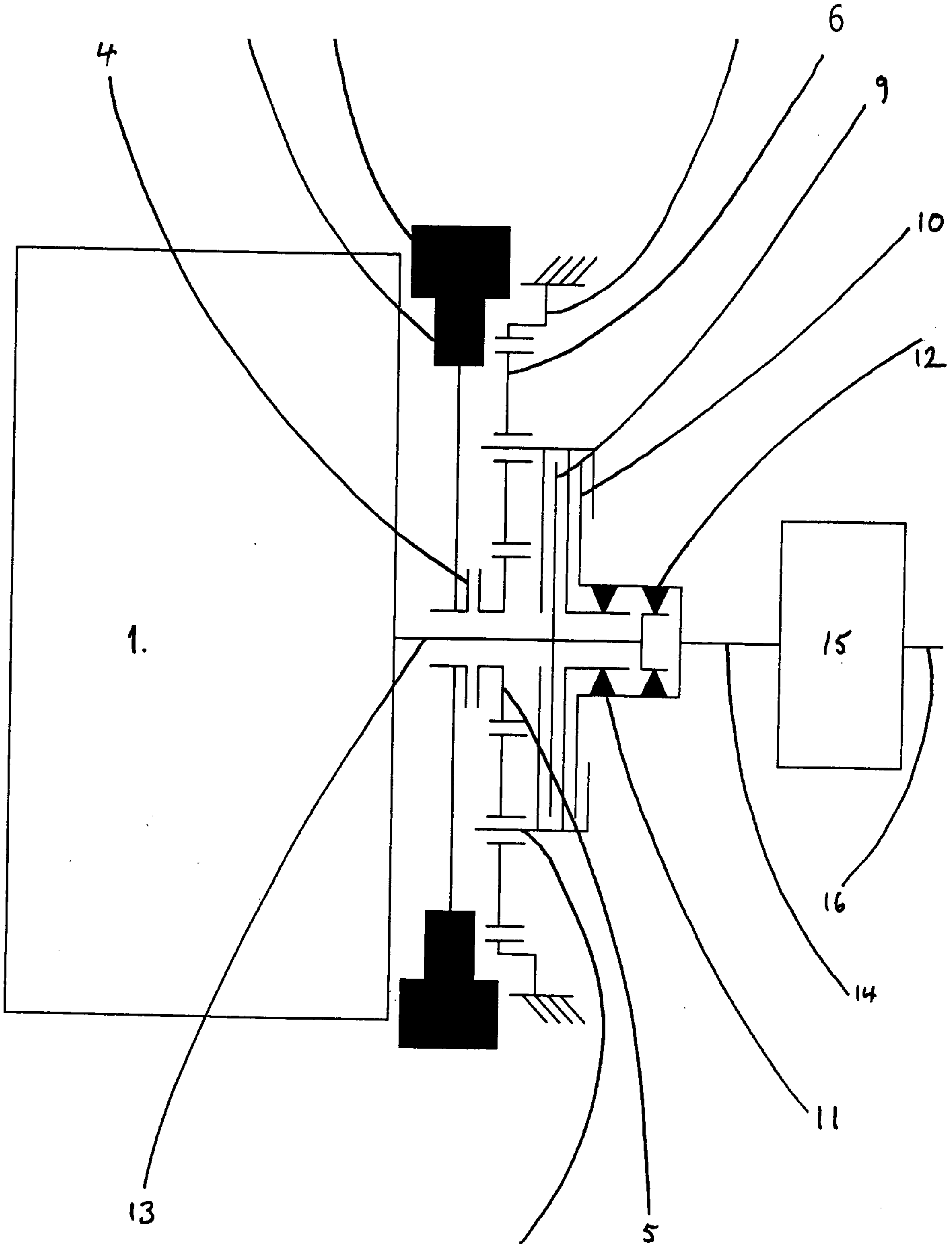


Fig 7.

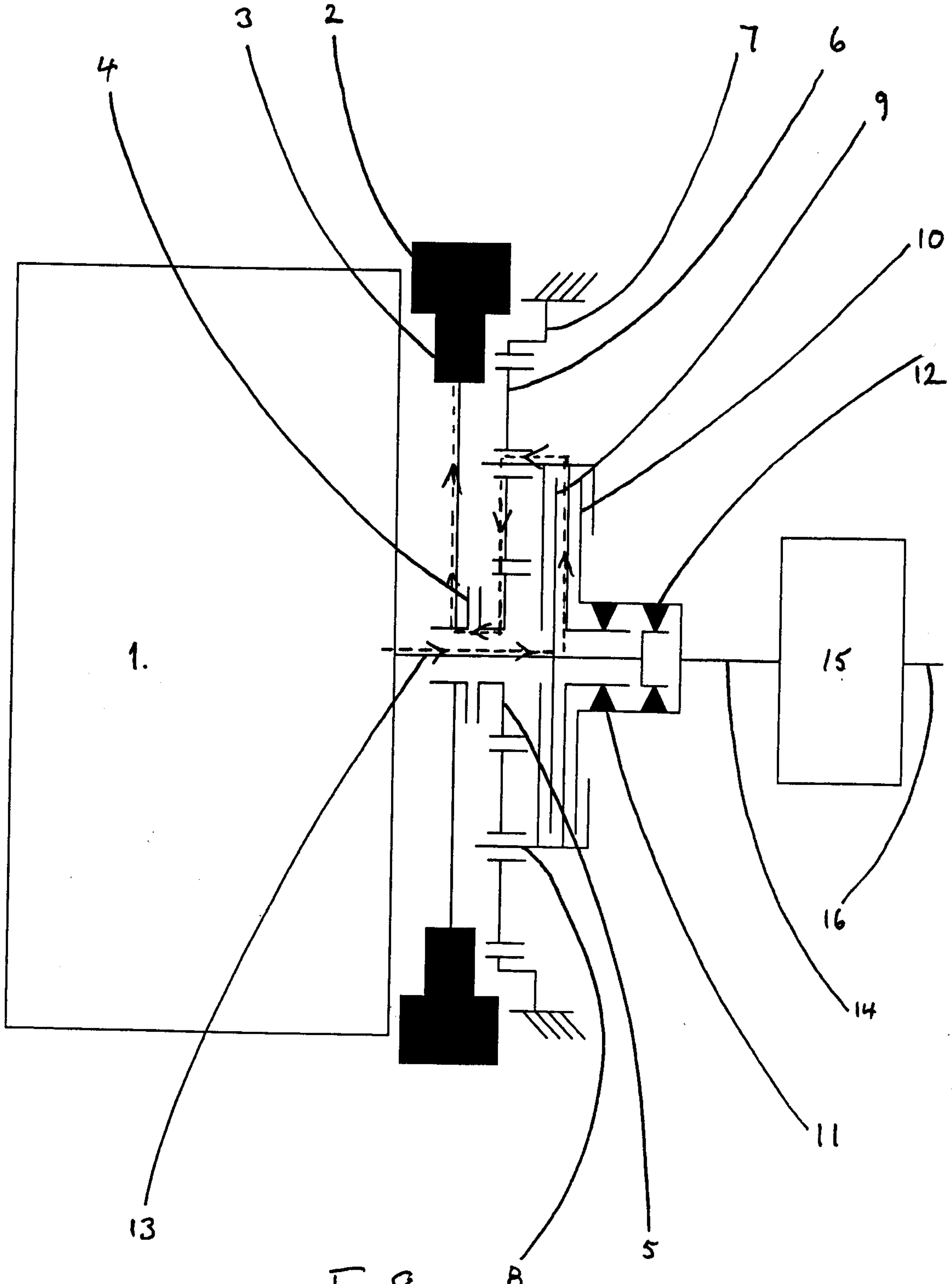


Fig 8.

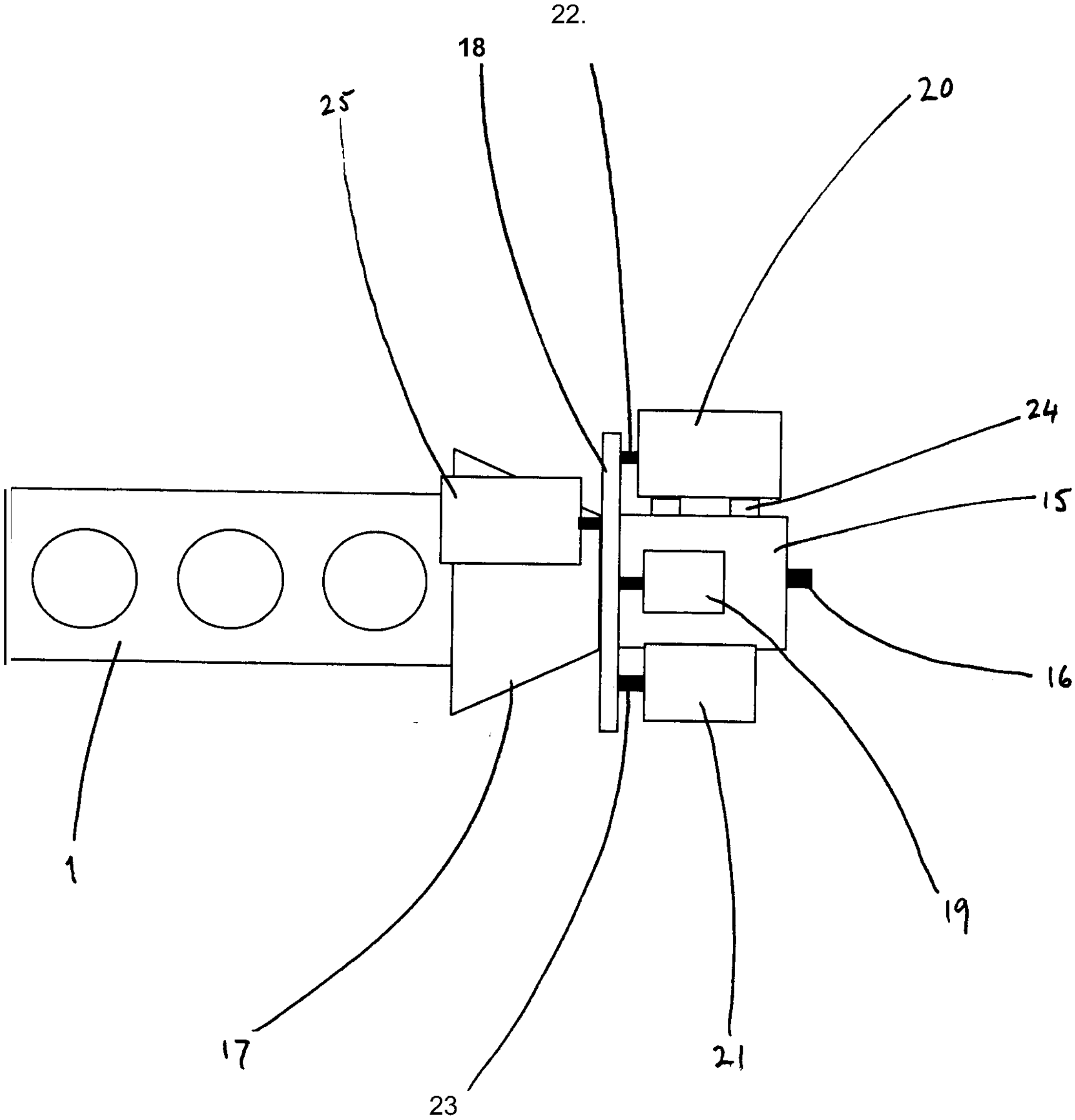


Fig.9

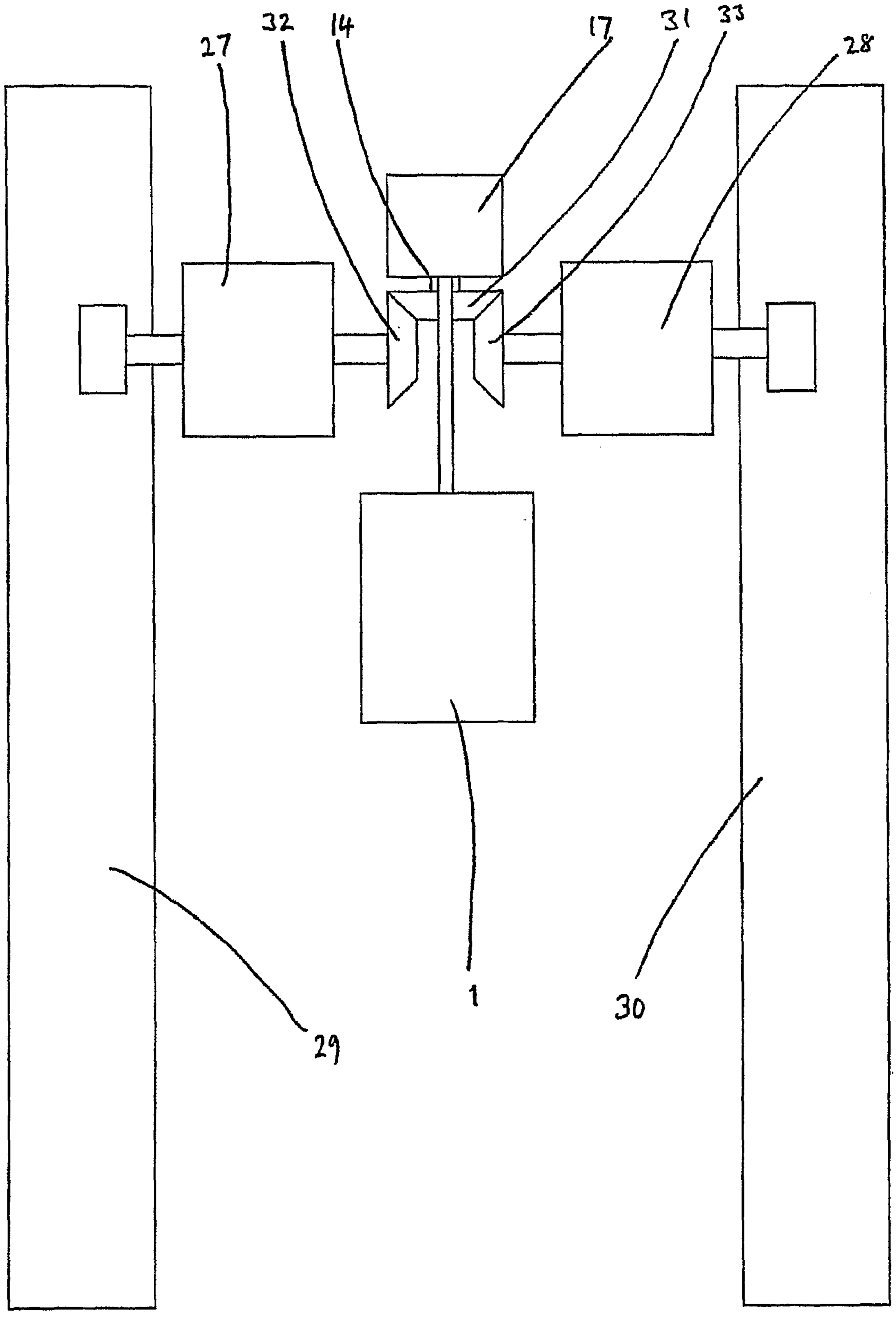


Fig.10