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(71) Applicant: **TOYOTA JIDOSHA KABUSHIKI KAISHA** [JP/JP]; 1, Toyota-cho, Toyota-shi, Aichi-ken, 471-8571 (JP).

(72) Inventors: **ITAGAKI, Kenji**; c/o Toyota Jidosha Kabushiki Kaisha, of 1, Toyota-cho, Toyota-shi, Aichi-ken, 471-8571 (JP). **MAGARIDA, Naofumi**; c/o Toyota Jidosha Kabushiki Kaisha, of 1, Toyota-cho, Toyota-shi, Aichi-ken, 471-8571 (JP). **HAKUMURA, Youmei**; c/o Aisin Aw Co., LTD., of 10, Takane, Fujii-cho, Anjo-shi, Aichi-ken, 444-1192 (JP).

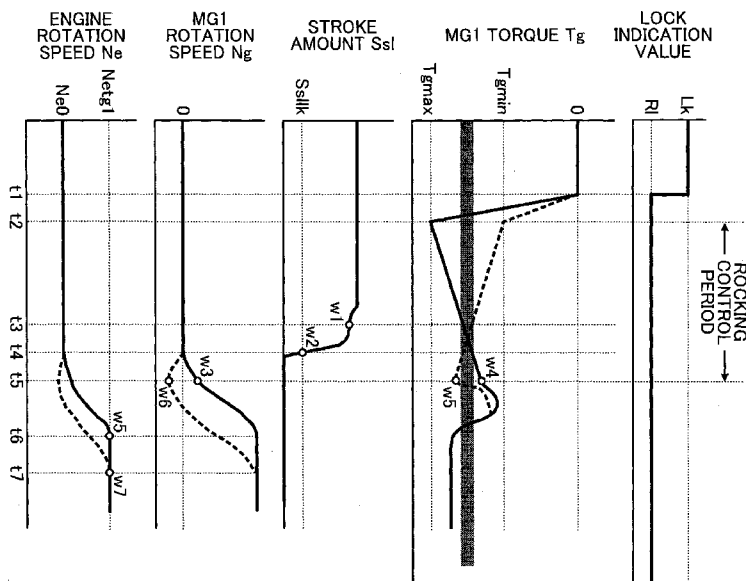
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(54) Title: CONTROL APPARATUS FOR HYBRID VEHICLE



(57) Abstract: An electronic control unit of a hybrid vehicle is configured to (i) control a rotating electrical machine (MG1) such that when an engagement mechanism (500) is switched from an engagement state to a release state, a counter torque that counteracts a torque of an internal combustion engine (200) applied to the one rotary element is output along with an increase or decrease in the counter torque; (ii) control the rotating electrical machine such that the counter torque is output to be decreased when a rotation speed of the internal combustion engine increases at or after a point of time at which the engagement mechanism is switched to the release state; and (iii) control the rotating electrical machine such that the counter torque is output to be increased when the rotation speed of the internal combustion engine decreases at or after the point of time at which the engagement mechanism is switched to the release state.

CONTROL APPARATUS FOR HYBRID VEHICLE

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

[0001] The invention relates to the technical field of control apparatuses for hybrid vehicles.

2. Description of Related Art

10 [0002] A hybrid vehicle is available that has a structure in which a differential mechanism, an internal combustion engine, and a rotating electrical machine are coupled with each other, a torque reaction of the internal combustion engine is received by the rotating electrical machine, and an operation point of the internal combustion engine is controlled. In the hybrid vehicle of this type, a rotary element of the differential
15 mechanism is restricted to a non-rotatable state by an engagement mechanism provided with a pair of engagement elements, and the torque reaction that has been borne by the rotating electrical machine is allotted to the engagement mechanism. A configuration is also available in which the system efficiency of a hybrid vehicle is thus increased. A meshing-type engagement mechanism which excels in power transmission efficiency, for
20 example, such as a dog clutch, can be advantageously used as the engagement mechanism of this type.

[0003] Where the meshing-type engagement mechanism is used, in a state in which a torque in the meshing direction of a pair of engagement elements acts upon the meshing elements, a stroke in the axial line direction of the engagement elements does not
25 proceed smoothly, and the engagement mechanism is not switched smoothly to a release state. Therefore, in order to facilitate the stroke in the axial line direction of the engagement elements when the engagement mechanism is switched to the release state, a torque that cancels the torque in the meshing direction of the engagement elements is output from a rotating electrical machine. Such control of the rotating electrical machine

is disclosed in Japanese Patent Application Publication No. 2012-193851 (JP 2012-193851 A).

[0004] With the meshing-type engagement mechanism disclosed in JP 2012-193851 A, rocking control is executed by which the torque is increased or decreased and one engagement element of the pair of engagement elements is rocked. Further, when the rocking control is executed, the torque of the electrical rotating machine is initially changed so as to approach a post-release requested torque which is requested for the rotating electrical machine after the engagement mechanism has been switched to the release state. As a result, the torque of the rotating electrical machine can be smoothly changed to the requested torque when the engagement mechanism is released. A similar meshing-type engagement device is also disclosed in Japanese Patent Application Publication No. 2009-029394 (JP 2009-029394 A).

[0005] A drive control apparatus for a vehicle has also been suggested in which a time required for a release is obtained from the change amount of a stroke in dog teeth at the time of engagement and release of an engagement mechanism, and a torque acting upon the dog teeth is estimated from the obtained time required for the release (see Japanese Patent Application Publication No. 2010-089575 (JP 2010-089575 A)).

[0006] A drive apparatus equipped with a meshing-type engagement device has also been suggested in which a learning correction amount of a changing speed of the torque of a first motor generator (MG) is determined according to operation conditions of an engine when the meshing-type engagement device is switched from the engagement state to the release state, and the changing speed is corrected (see Japanese Patent Application Publication No. 2009-286356 (JP 2009-286356 A)).

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SUMMARY OF THE INVENTION

[0007] A request to switch to a release state is often initiated due to changes in operation conditions of a vehicle, for example, an acceleration request or a deceleration request. Thus, the rotation speed of an internal combustion engine often increases or decreases after the engagement mechanism has been switched to the release state.

[0008] In particular, in the above-described conventional devices, changes in the rotation speed of the internal combustion engine after the completion of switching to the release state are not reflected in the change direction of the torque of the rotating electrical machine in the switching period of time. Therefore, in the conventional devices, the change of the rotation speed of the internal combustion engine can be inhibited by the torque of the rotating electrical machine and the rotation speed of the internal combustion engine can fluctuate after the completion of switching to the release state.

[0009] The invention provides a control apparatus for a hybrid vehicle that can suppress the fluctuation of the rotation speed of the internal combustion engine when the engagement mechanism is switched to the release state.

[0010] An aspect of the invention relates to a control apparatus for a hybrid vehicle. The hybrid vehicle includes an internal combustion engine, a rotating electrical machine, a drive wheel, a drive shaft, a differential mechanism, and an engagement mechanism. The drive shaft is configured to be coupled to the drive wheel. The differential mechanism includes a plurality of rotary elements performing mutually differential operations. The internal combustion engine, the rotating electrical machine, and the drive shaft are each coupled to the plurality of rotary elements. The engagement mechanism includes a pair of meshing engagement elements. In an engagement state in which the pair of engagement elements is engaged, the engagement mechanism is configured to fix non-rotatably one rotary element of the plurality of rotary elements such that a rotation of the rotating electrical machine is restricted in comparison with when the one rotary element from among the plurality of rotary elements is not fixed non-rotatably. The control apparatus includes an electronic control unit. The electronic control unit is configured to (i) control the rotating electrical machine such that when the engagement mechanism is switched from the engagement state to a release state in which the pair of engagement elements is released, a counter torque that counteracts a torque of the internal combustion engine applied to the one rotary element is output along with an increase or decrease in the counter torque; (ii) control the rotating electrical machine such that the counter torque is output to be decreased when a rotation speed of the internal combustion

engine increases at or after a point of time at which the engagement mechanism is switched to the release state; and (iii) control the rotating electrical machine at or after such that the counter torque is output to be increased of increasing when the rotation speed of the internal combustion engine decreases at or after the point of time at which the engagement
5 mechanism is switched to the release state.

[0011] According to the abovementioned aspect, a counter torque that counteracts the torque of the internal combustion engine (that is, acts in a direction opposite that of the torque of the internal combustion engine) is output from the rotating electrical machine when the engagement mechanism is switched from the engagement state to the release
10 state. The counter torque relaxes the engagement torque acting between the pair of engagement elements in the engagement mechanism and facilitates the cancelation of the engagement of the pair of engagement elements (that is, a stroke in axial line direction of one engagement element). For the sake of convenience, the torque of the rotating electrically machine will be referred to hereinbelow, as appropriate, as "release torque".

[0012] The release torque is output in a change direction, rather than as a fixed value, namely, to be increased (since the release torque is a negative torque, a direction of decreasing where the sign is taken into account) which is a change direction such that the absolute value of the release torque increases (likewise, the release torque decreases where the sign is taken into account), or to be decreased (since the release torque is a negative
20 torque, a direction of increasing where the sign is taken into account) which is a change direction such that the absolute value of the release torque decreases (likewise, the release torque increases where the sign is taken into account). The so called "rocking control" is realized by changing the release torque.

[0013] In the hybrid vehicle according to the invention, the differential
25 mechanism plays the role of a transmission. Thus, where the engagement mechanism is in the release state, the rotating electrical machine bears the reaction torque of the torque of the internal combustion engine through the rotary element of the differential mechanism, thereby making it possible to control the rotation speed of the internal combustion engine. Thus, the reaction torque borne by the rotating electrical machine affects changes in the

rotation speed of the internal combustion engine. Meanwhile, it is sometimes necessary to change the rotation speed of the internal combustion engine toward a target value at or after a point of time at which the engagement mechanism is switched to the release state. In this case, where the release torque is output in the direction of increasing such that the absolute value thereof increases while the rotation speed of the engine is required to be increased, the release torque (at or after a point of time of switching to the release state, the release torque is substantially equivalent to the reaction torque) acts in the direction of suppressing the increase in the engine rotation speed. Conversely, where the release torque is output in the direction of decreasing while the rotation speed of the engine is required to be decreased, the release torque acts in the direction of suppressing the decrease in the engine rotation. Such action of the release torque inhibits the change in the engine rotation speed toward the target rotation speed and, therefore, can cause fluctuations of the engine rotation speed.

[0014] According to the abovementioned aspect, the change direction of the release torque in the rocking control is herein controlled. More specifically, when the rotation speed of the internal combustion engine increases at or after a point of time at which the engagement mechanism is switched to the release state, the release torque is output to be decreased. Meanwhile, when the rotation speed of the internal combustion engine decreases at or after the point of time at which the engagement mechanism is switched to the release state, the release torque is output to be increased. Therefore, according to the abovementioned aspect, the release torque can be changed in a direction of not interfering with the change in the rotation speed of the internal combustion engine at or after the completion of switching to the release state, and fluctuations of the engine rotation speed associated with the switching of the engagement mechanism to the release state can be suppressed. The change direction of the release torque is controlled, for example, based on an accelerator operation state. The accelerator operation state, as referred to herein, is the operation state of an accelerator pedal and is a factor defining the change direction of the rotation speed of the internal combustion engine at or after a point of time at which the engagement mechanism is switched to the release state. The

accelerator operation state can include a state corresponding to an accelerator depression operation (essentially, corresponds to an acceleration request) accompanied by the increase in the engine rotation speed and a state corresponding to an accelerator return operation (essentially, corresponds to a deceleration request) accompanied by the decrease in the engine rotation speed. For example, the ECU controls the rotating electrical machine such that the release torque is output to be decreased when the accelerator operation corresponds to an accelerator depression operation. For example, the ECU controls the rotating electrical machine such that the release torque is output to be increased when the accelerator operation corresponds to an accelerator return operation. Therefore, the increase in the engine rotation speed at or after the completion of switching of the engagement mechanism to the release state is not inhibited and fluctuations of the engine rotation speed are advantageously suppressed. Whether or not the accelerator operation state corresponds to the accelerator depression operation may be determined in advance, based on whether or not an accelerator depression amount or an accelerator depression amount change rate which defines the operation state of the accelerator pedal is a value that is accompanied by the increase in the engine rotation speed.

[0015] From a practical point of view, whether or not the switching to the release state is completed, usually may be determined on the basis of the rotation state of the rotating electrical machine. Therefore, a point of time at which it is determined that the switching to the release state has been completed is later than a point of time at which the engagement mechanism actually moves to the release state (in other words, a point of time at which the meshing of the engagement elements is released). Therefore, the output of the release torque from the rotating electrical machine may be continued within an interim period after a point of time at which the engagement mechanism actually moves to the release state. As a result, where the change direction of the release torque is the direction of interfering with the change in the rotation speed of the internal combustion engine, the scale of fluctuations of the engine rotation speed can easily become relatively large. Meanwhile, where the change direction of the release torque does not interfere with the change in the engine rotation speed, the change in the engine rotation speed is not inhibited

even in the interim period.

[0016] In the aspect, the ECU may be configured to estimate the torque of the internal combustion engine. The torque may be applied to the one rotary element. The ECU may be configured to change the counter torque within an estimated error range including the estimated torque.

[0017] By contrast with the release state in which the actual torque of the internal combustion engine can be estimated with a comparatively high accuracy by using the reaction torque of the rotating electrical machine having torque controllability of a comparatively high accuracy, where the engagement mechanism is in the engagement state, the real torque of the internal combustion engine which has relatively low torque controllability is difficult to estimate accurately. It is also not easy to estimate accurately the torque of the internal combustion engine which is distributed at a constant ratio to one rotary element of the differential mechanism relating to the engagement of a pair of engagement elements. Therefore, there exists an estimated error range including an estimated value for the torque estimated by the ECU. This estimated error range can be set in advance experimentally, empirically, or theoretically, for example, in the form of an error torque or an error ratio with respect to the estimated value.

[0018] According to the aspect, the release torque of the rotating electrical machine is changed in the direction of increasing or decreasing within the estimated error range thereof. Therefore, it is possible to provide a constant indicator for change range of the release torque, and the release torque can be advantageous caused to reach an equilibrium value suitable for releasing the pair of engagement elements.

[0019] In the abovementioned aspect, the ECU may be configured to control the internal combustion engine and the rotating electrical machine such that an operation point of the internal combustion engine is a target operation point on a predetermined operation line when the engagement mechanism is in the release state. The ECU may be configured to control the rotating electrical machine, based on the target operation point, such that the counter torque is output to be decreased when the rotation speed of the internal combustion engine increases at or after a point of time at which the engagement mechanism is switched

to the release state. The ECU may be configured to control the rotating electrical machine such that the counter torque is output to be increased when the rotation speed of the internal combustion engine decreases at or after the point of time at which the engagement mechanism is switched to the release state.

5 **[0020]** In a hybrid vehicle using a differential mechanism as a kind of transmission, a kind of electrical continuously variable transmission (electrical CVT) is realized when the engagement mechanism is in the release state. In this case, the operation point of the internal combustion engine which is defined by the engine rotation speed and torque is set on an operation line satisfying the desired property (for example, an
10 optimum fuel consumption line on which the fuel consumption ratio of the internal combustion engine is realistically minimized). Therefore, whether or not an increase or a decrease in the rotation speed of the internal combustion engine occurs after a point of time at which the switching to the release state is completed can be determined, based on the operation line and the required output of the internal combustion engine.

15 **[0021]** According to the aspect, the change direction of the release torque can be controlled with a higher accuracy, and fluctuations of the engine rotation speed can be suppressed more accurately, based on the determination as to whether or not the engine rotation speed actually increases or decreases.

20 **[0022]** Such operations and other advantages of the invention will be made apparent from the below-described embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

25 **[0023]** Features, advantages, and technical and industrial significance of exemplary embodiments of the invention will be described below with reference to the accompanying drawings, in which like numerals denote like elements, and wherein:

FIG. 1 is a schematic configuration diagram representing schematically the configuration of a hybrid vehicle according to a first embodiment of the invention;

FIG. 2 is a schematic configuration diagram representing schematically the configuration of a hybrid drive device in the hybrid vehicle depicted in FIG. 1;

FIGS. 3A is a schematic plan view of a dog clutch mechanism in the hybrid vehicle depicted in FIG. 1;

FIGS. 3B is a schematic plan view of a dog clutch mechanism in the hybrid vehicle depicted in FIG. 1;

5 FIGS. 4A is operation collinear diagrams illustrating speed change modes of the hybrid vehicle depicted in FIG. 1;

FIGS. 4B is operation collinear diagrams illustrating speed change modes of the hybrid vehicle depicted in FIG. 1;

FIG. 5 is a flowchart of MG1 release control in the hybrid vehicle depicted in FIG. 1;

10 FIG. 6 illustrates an example of a temporal transition of operation states of parts of a hybrid vehicle in relation to the effect of the MG1 release control depicted in FIG. 5;

FIG. 7 is a flowchart of MG1 release control relating to a second embodiment of the invention;

FIG. 8 is a schematic diagram of the operation point plane of the engine;

15 FIG. 9 is a schematic configuration diagram of a power split mechanism according to a variation example; and

FIG. 10 is an operation collinear diagram corresponding to a locked state in the power splitting mechanism depicted in FIG. 9.

20 DETAILED DESCRIPTION OF EMBODIMENTS

[0024] The preferred embodiments of the invention are explained hereinbelow with reference to the appended drawings. Initially, the configuration of a hybrid vehicle 1 according to the first embodiment of the invention is explained with reference to FIG. 1. FIG. 1 is a schematic configuration diagram representing schematically the configuration
25 of the hybrid vehicle 1.

[0025] In FIG. 1, the hybrid vehicle 1 is an example of the "hybrid vehicle" according to the invention, the hybrid vehicle including an ECU 100, a power control unit (PCU) 11, a battery 12, a vehicle speed sensor 13, an accelerator depression amount sensor 14, and a hybrid drive device 10.

[0026] The ECU 100 is provided with a central processing unit (CPU), a read only memory (ROM), and a random access memory (RAM). The ECU 100 is configured to be capable of controlling the operation of various parts of the hybrid vehicle 1. The ECU 100 is an example of the "control apparatus for a hybrid vehicle" according to the invention. The ECU 100 is configured to be capable of executing various types of control such as the below-described MG1 release control according to a control program stored in the ROM.

[0027] The ECU 100 is provided with a clutch control unit 110 and a drive control unit 120. The clutch control unit 110 controls the operation state of the below-described dog clutch mechanism 500. The drive control unit 120 controls the power state of an engine 200, a first motor generator MG1, and a second motor generator MG2 described hereinbelow. The clutch control unit 110 and the drive control unit 120 operate according to respective control programs that have been stored in advance, and control the operation state of the hybrid vehicle 1 while cooperating, as appropriate, with other control units (not shown in the figure). In the below-described MG1 release control, the clutch control unit 110 executes control in cooperation with the drive control unit 120. Such a configuration of the ECU 100 is merely exemplary.

[0028] The PCU 11 includes an inverter (not shown in the figure). The inverter is configured to be capable of converting direct current (DC) power taken out from the battery 12 into alternating current (AC) power and supplying the converted power to the first motor generator MG1 and the second motor generator MG2 described hereinbelow. The inverter is also configured to be capable of converting AC power generated by the first motor generator MG1 and the second motor generator MG2 into DC power and supplying the converted power to the battery 12. The PCU 11 is a control unit configured to be capable of controlling power exchange between the battery 12 and, the first motor generator MG1 and the second motor generator MG2 or between the first motor generator MG1 and the second motor generator MG2. The PCU 11 is electrically connected to the ECU 100 and configured such that the operation thereof is controlled by the ECU 100.

[0029] The battery 12 is a rechargeable power storage unit configured to function

as a power supply source with respect to power for powering the first motor generator MG1 and the second motor generator MG2. For example, the battery 12 has a configuration in which several hundreds of unit secondary battery cells with an output voltage V_s are connected in series.

5 [0030] The vehicle speed sensor 13 is configured to be capable of detecting the vehicle speed V of the hybrid vehicle 1. The vehicle speed sensor 13 is electrically connected to the ECU 100, and the detected vehicle speed V is referred to, as appropriate, in the ECU 100.

10 [0031] The accelerator depression amount sensor 14 is configured to be capable of detecting an accelerator depression amount T_a which is the operation amount of an accelerator pedal (not shown in the figure) of the hybrid vehicle 1. The accelerator depression amount sensor 14 is electrically connected to the ECU 100, and the detected accelerator depression amount T_a is referred to, as appropriate, in the ECU 100.

15 [0032] The hybrid drive device 10 is a power train of the hybrid vehicle 1. The hybrid drive device 10 is configured to be capable of transmitting the power supplied from the below-described engine 200, the first motor generator MG1 and the second motor generator MG2 to a wheel shaft V_S coupled to drive wheel DW .

20 [0033] The detailed configuration of the hybrid drive device 10 is explained hereinbelow with reference to FIG. 2. FIG. 2 is a schematic configuration diagram representing schematically the configuration of the hybrid drive device 10. In the figure, components same as those in FIG. 1 are assigned with the same reference numerals and the explanation thereof is omitted as appropriate.

25 [0034] In FIG. 2, the hybrid drive device 10 includes the engine 200, a power split mechanism 300, the first motor generator MG1, the second motor generator MG2, a reduction mechanism 400, and the dog clutch mechanism 500.

[0035] The engine 200 is a gasoline engine which is an example of the "internal combustion engine" according to the invention. The engine is configured to function as a power source for the hybrid vehicle 1. The "internal combustion engine" according to the invention is a general concept inclusive of engines that can convert thermal energy

generated by fuel combustion into mechanical energy and take out the converted energy. The configuration of the internal combustion engine according to the invention may be of a variety of conventional or unconventional forms, provided that the configuration is within the aforementioned concept. An engine torque T_e serving as output power of the engine
5 200 is input through a crankshaft (not shown in the figure) to an input shaft IS of the hybrid drive device 10.

[0036] Returning to FIG. 2, the first motor generator MG1 is an example of the "rotating electrical machine" according to the invention and is configured to have a powering function of converting electrical energy into mechanical energy and a
10 regenerative function of converting mechanical energy into electrical energy.

[0037] Similarly to the first motor generator MG1, the second motor generator MG2 is also configured to have a powering function of converting electrical energy into mechanical energy and a regenerative function of converting mechanical energy into electrical energy. The first motor generator MG1 and the second motor generator MG2
15 are configured as synchronous motor generators and also configured, for example, to include a rotor having a plurality of permanent magnets on the outer circumferential surface and a stator onto which three-phase coils forming a rotating magnetic field are wound. Motor generators of other configurations may be also used.

[0038] The power split mechanism 300 is a planetary gear mechanism which is an
20 example of the "differential mechanism" according to the invention. The power split mechanism 300 includes a sun gear S1 provided in the center, a ring gear R1 provided concentrically on the outer circumference of the sun gear S1, a plurality of pinion gears P1 disposed between the sun gear S1 and the ring gear R1, each pinion gear revolving, while rotating, about the sun gear S1 on the outer circumference thereof, and a planetary carrier
25 C1 that supports rotating shafts of the pinion gears. The rotary elements, namely, the sun gear S1, the ring gear R1, and the planetary carrier C1, function as differential elements of the power split mechanism 300.

[0039] The sun gear S1 is coupled through a sun gear shaft SS to the first motor generator MG1. The rotation speed of the sun gear S1 is equal to a rotation speed N_g of

the first motor generator MG1. The rotation speed Ng of the first motor generator MG1 is the rotation speed of the MG1.

[0040] The ring gear R1 is coupled through a drive shaft DS and the reduction mechanism 400 to a wheel shaft VS. The reduction mechanism 400 is a gear mechanism constituted by various reduction gears including a differential gear. Therefore, the rotation speed of the ring gear R1 takes a unique value with respect to the vehicle speed V. Since the second motor generator MG2 is also coupled to the drive shaft DS, the rotation speed of the ring gear R1 is equal to a rotation speed Nm of the second motor generator MG2. The rotation speed Nm of the second motor generator MG2 is the rotation speed of the MG2. Therefore, rotation speed Nm of the second motor generator MG2 also takes a unique value with respect to the vehicle speed V. In the embodiment the second motor generator MG2 is configured to be directly connected to the drive shaft DS. An appropriate speed change device or reduction device may be also disposed between the drive shaft DS and the second motor generator MG2.

[0041] The planetary carrier C1 is coupled to the abovementioned IS. Therefore, the rotation speed of the planetary carrier C1 is equal to an engine rotation speed Ne which is the rotation speed of the engine 200.

[0042] The power split mechanism 300, which has the above-described configuration, is configured such that the engine torque Te is distributed at a predetermined ratio (ratio corresponding to the gear ratio of respective gears) to the sun gear S1 and the ring gear R1 through the planetary carrier C1 and the pinion gears P1.

[0043] In order to facilitate the understanding of the operation of the power split mechanism 300, where a gear ratio ρ is defined as a ratio of the number of teeth in the sun gear S1 to the number of teeth in the ring gear R1, a sun gear shaft torque Tes acting upon the sun gear S1 when the engine torque Te acts from the engine 200 upon the planetary carrier C1 can be represented by the following Expression (1). A drive shaft direct torque Tep that appears on the drive shaft DS can be represented by the following Expression (2).

$$[0044] \quad T_{es} = T_e \times \rho / (1 + \rho) \quad \dots(1)$$

$$T_{ep} = T_e \times 1 / (1 + \rho) \quad \dots(2)$$

The dog clutch mechanism 500 is a clutch device of a rotation meshing which is an example of the "engagement mechanism" according to the invention. The dog clutch mechanism is provided with a plurality of engagement elements and configured such that the plurality of engagement elements can be engaged with and disengaged from each other.

5 **[0045]** The dog clutch mechanism 500 is provided as a pair of engagement elements, for example, with an annular sleeve SL that is fixed non-rotatably to a fixing element such as a chassis or a transmission case, and a hub HB that is fixed to the sun gear shaft SS and rotates integrally with the sun gear shaft SS. The annular sleeve SL and the hub HB are arranged coaxially. Further, rectangular dog teeth 510 are provided
10 equidistantly on the inner circumferential surface of the annular sleeve SL, and rectangular dog teeth 520 are provided equidistantly on the outer circumferential surface of the hub HB.

[0046] The annular sleeve SL can be caused to perform reciprocating motion (stroke) through a predetermined distance in the axial direction of the annular sleeve SL by
15 an actuator (not shown in the figure) which is drive controlled by the clutch control unit 110 of the ECU 100. Where a stroke amount Ssl of the annular sleeve SL reaches a predetermined engagement stroke amount Sslk, the dog teeth 510 provided at the annular sleeve SL mesh with the dog teeth 520 provided at the hub HB. As a result, the dog clutch mechanism 500 assumes the engagement state. In the engagement state, the hub
20 HB is fixed through the annular sleeve SL to the fixing element. Therefore, the sun gear shaft SS is locked non-rotatably. As a result, the first motor generator MG1 is in a non-rotatable locked state.

[0047] Meanwhile, where the stroke amount Ssl is less than the engagement stroke amount Sslk, the dog teeth are disengaged from each other. Therefore, the dog
25 clutch mechanism 500 is in the release state. In the release state, the hub HB is not fixed through the annular sleeve SL to the fixing elements. Thus, the sun gear shaft SS can rotate. As a result, the first motor generator MG1 also can rotate.

[0048] The dog clutch mechanism 500 is an example of the "engagement mechanism" according to the invention which is provided with the annular sleeve SL and

the hub HB as the "meshing-type engagement elements" according to the invention. The engagement mechanism according to the invention is, however, a general concept inclusive of a variety of engagement mechanisms in which engagement is performed by meshing of a pair of engagement elements.

5 [0049] The operation state of the dog clutch mechanism 500 is explained herein with reference to FIG. 3. FIG. 3 is a schematic plan view of the dog clutch mechanism 500. In FIG. 3, components same as those in FIG. 2 are assigned with the same reference numerals and the explanation thereof is omitted as appropriate.

10 [0050] In FIG. 3, FIG. 3A corresponds to the release state, and FIG. 3B corresponds to the engagement state.

 [0051] In FIG. 3A, the annular sleeve SL provided with the plurality of dog teeth 510 can be moved by the drive force of the actuator from the position with the stroke amount $S_{sl} = 0$, which corresponds to the release state, to the position with the maximum stroke amount $S_{sl} = S_{slmax}$ in the direction shown by the arrow in the figure.

15 [0052] FIG. 3B depicts the state in which the annular sleeve SL has reached the position with the maximum stroke amount $S_{sl} = S_{slmax}$. However, the engagement of the annular sleeve SL and the hub HB (that is, the below-described locking of the first motor generator MG1) is established when the annular sleeve SL is moved to a position with a stroke amount $S_{sl} = S_{slk}$ ($0 < S_{slk} < S_{slmax}$).

20 [0053] The annular sleeve SL and the hub HB are engaged with each other by the movement of the annular sleeve SL after the rotation speed synchronization and rotation phase synchronization of the annular sleeve SL and the hub HB have been performed such that the dog teeth provided thereon mesh together. The stroke of the annular sleeve SL, the rotation speed synchronization and rotation phase synchronization may be performed at
25 the same time.

 [0054] Where the annular sleeve SL and the hub HB are engaged, the aforementioned sun gear shaft torque T_{es} acting in the direction D2 shown in the figure can be taken by the fixing element through the annular sleeve SL. Therefore, with the object of reducing power consumption, the first motor generator MG1 is controlled to a shutdown

state in which the energizing is stopped or to a zero torque state in which the energizing is maintained. Meanwhile, since no torque is output from the first motor generator MG1, where the dog clutch mechanism 500 is in the engagement state, gaps (mechanical backlash) appearing between the dog teeth 510 and the dog teeth 520 are closed in the direction D2 which is the action direction of the sun gear shaft torque T_{es} .

[0055] The speed change mode of the hybrid vehicle 1 according to the embodiment is controlled to either a fixed speed change mode or a stepless speed change mode according to the operation state of the dog clutch mechanism 500.

[0056] The speed change mode of the hybrid vehicle 1 is explained hereinbelow with reference to FIG. 4. FIG. 4 shows operation collinear diagrams of the hybrid drive device 10. In the figure, components same as those in FIG. 2 are assigned with the same reference numerals and the explanation thereof is omitted as appropriate.

[0057] FIG. 4A is an operation collinear diagram corresponding to the stepless speed change mode; the rotation speed is plotted against the ordinate in FIG. 4A.

[0058] The power split mechanism 300 is a differential mechanism with two rotational degrees of freedom which is constituted by three rotary elements which are in a differential relationship with each other. The power split mechanism 300 is configured such that where the rotation speeds of two elements from among the sun gear S1 (primarily, the first motor generator MG1), the carrier C1 (primarily, the engine 200), and the ring gear R1 (primarily, the second motor generator MG2) are set, the rotation speed of the remaining one rotary element is necessarily set. Thus, on the operation collinear diagram, the operation state of each rotary element can be represented by an operation colline in one-to-one correspondence to the operation state of the hybrid drive device 10.

[0059] For example, in FIG. 4A, an operation point m1 is taken as the operation point of the second motor generator MG2 which is in unique relationship with the vehicle speed V . In this case, where the operation point of the first motor generator MG1 is an operation point g1, the operation point of the engine 200 coupled to the carrier C1, which is the remaining rotary element, is an operation point e1.

[0060] In this case, where the rotation speed of the ring gear R1 is assumed to be

constant for the sake of convenience, when the operation point of the first motor generator MG1 is changed from the operation point g1 to an operation point g2 and an operation point g3, the operation point of the engine 200 changes from the operation point e1 to an operation point e2 and an operation point e3. Thus, in the power split mechanism 300, the engine rotation speed N_e can be freely changed by the first motor generator MG1. The speed change mode corresponding to this state is the stepless speed change mode. In the stepless speed change mode, the operation point of the engine 200 is basically controlled to an optimum power consumption operation point in which the fuel consumption ratio of the engine 200 is substantially minimized. The operation point in this case means that an operation condition of the engine 200 that is defined by the combination of the engine rotation speed N_e and the engine torque T_e .

[0061] In the stepless speed change mode, the MG1 rotation speed N_g is variable. Therefore, when the stepless speed change mode is selected, the dog clutch mechanism 500 is controlled to the release state.

[0062] In order to supply the abovementioned drive shaft direct torque T_{ep} to the drive shaft DS in the power split mechanism 300, a reaction torque (that is, a negative torque) which has the same absolute value as the above-mentioned sun gear shaft torque T_{es} , but the opposite sign, should be supplied to the first motor generator MG1. In this case, in an operation point in a positive rotation region, for example, the operation point g1 or the operation point g2, the first motor generator MG1 is in a power regeneration state with a positive-rotation negative torque (that is, a power generation state). Thus, in the stepless speed change mode, by causing the first motor generator MG1 to function as a reaction element, it is possible to generate power by using the sun gear shaft torque T_{es} while supplying the drive shaft direct torque T_{ep} , which is part of the engine torque T_e , to the drive shaft DS. Further, for example, when the drive shaft direct torque T_{ep} supplied to the drive shaft DS is insufficient as a required torque, a MG2 torque T_m which is the output torque of the second motor generator MG2 is supplied to the drive shaft DS and the torque assist is performed as appropriate.

[0063] Meanwhile, for example, in a high-speed low-load traveling mode, the

MG1 rotation speed N_g can take a value, for example, in a negative rotation region corresponding to the operation point g_3 . Since the first motor generator MG1 outputs a negative torque as a reaction torque with respect to the sun gear shaft torque T_{es} , the first motor generator MG1 in this state assumes a powering state with a negative rotation and negative torque. Thus, in this case, the MG1 torque T_g which is the output torque of the first motor generator MG1 is transmitted as the drive torque of the hybrid vehicle 1 to the drive shaft DS.

[0064] Therefore, the second motor generator MG2 is controlled to a power regeneration state with the positive rotation and negative torque that should absorb the extra torque output to the drive shaft DS. In this state, the MG1 torque T_g is used for power regeneration in the MG2, the first motor generator MG1 is driven in a powering mode by the regenerated power, and an inefficient electrical path which is called power circulation is formed. When power circulation occurs, the energy efficiency of the hybrid vehicle 1 decreases.

[0065] Accordingly, in the hybrid vehicle 1, for example, in the operation region which has been set in advance such that the aforementioned power circulation can occur, the dog clutch mechanism 500 is controlled by the clutch control unit 110 to the engagement state.

[0066] FIG. 4B depicts a state in which the dog clutch mechanism 500 is controlled by the clutch control unit 110 to the engagement state. Where the dog clutch mechanism 500 assumes the engagement state and the first motor generator MG1 is locked non-rotatably, the operation point of the first motor generator MG1 is fixed to an operation point g_0 depicted in FIG. 4B.

[0067] In this case, the remaining engine rotation speed N_e is uniquely determined by the MG1 rotation speed N_g ($N_g = 0$) and the MG2 rotation speed N_m which uniquely corresponds to the vehicle speed V (see point e_0 in the figure). Thus, where the first motor generator MG1 assumes the locked state, the speed ratio which is the speed ratio of the engine rotation speed N_e and the MG2 rotation speed N_m which uniquely corresponds to the vehicle speed V becomes constant. The speed change mode

corresponding to such a locked state is the fixed speed change model. In the fixed speed change mode, the reaction torque counteracting the sun gear shaft torque T_{es} can be taken through the dog clutch mechanism 500. Therefore, the supply of electrical power from the battery to the first motor generator MG1 can be shut down. As a result of reducing the electrical loss in the hybrid drive device 10, the energy efficiency can be increased.

[0068] In the locked state of the first motor generator MG1, the sun gear shaft torque T_{es} which acts in the direction D2 shown in the figure between the dog teeth 510 of the annular sleeve SL and the dog teeth 520 of the hub HB acts as the engagement torque of the annular sleeve SL and the hub HB.

[0069] In a state in which the engagement torque acts upon the annular sleeve SL and the hub HB, even when the annular sleeve SL is to be moved in the release direction toward a position corresponding to the stroke amount $S_{sl} = 0$ to release the engagement of the annular sleeve SL and the hub HB, it is difficult to cause the annular sleeve SL to move smoothly. Therefore, when switching the dog clutch mechanism 500 from the engagement state to the release state, measures should be taken to facilitate a smooth stroke of the annular sleeve SL. In the embodiment, such measures are realized by the MG1 release control executed by the ECU 100.

[0070] The MG1 release control is explained hereinbelow with reference to FIG. 5. FIG. 5 is a flowchart of the MG1 release control. The MG1 release control is performed by the clutch control unit 110 when the dog clutch mechanism 500 is in the engagement state and the release condition of the dog clutch mechanism 500 is fulfilled. Thus, the release control is performed by the clutch control unit 110 when a switching request to switch the speed change mode to the stepless speed change mode is issued. The clutch control unit 110 executes, as appropriate, the MG1 release control in coordination with the drive control unit 120.

[0071] A variety of usual conditions can be used by the clutch control unit 110 as a condition for switching the dog clutch mechanism 500 between the engagement state and the release state (in order words, switching the speed change mode between the stepless speed change mode and the fixed speed change mode).

[0072] In FIG. 5, where the MG1 release control is started, it is determined whether or not the accelerator depression amount T_a has increased (step S110). Whether or not the accelerator depression amount T_a has increased is determined on the basis of an accelerator depression amount change rate R_{ta} which is a temporal change rate of the accelerator depression amount T_a detected by the accelerator depression amount sensor 14. Thus, where the accelerator depression amount change rate R_{ta} takes a positive value (that is, the condition of $R_{ta} > 0$ is fulfilled), it is determined that the accelerator depression amount T_a has increased. The condition of $R_{ta} > 0$ is used herein, but the determination may be also performed on the basis of the quantitative relationship with a threshold defining a kind of a dead zone with the object of avoiding an excessive response to fluctuations of the acceleration operation or small changes in acceleration unintended by the driver.

[0073] Where it is determined that the accelerator depression amount T_a has increased (step S110: YES), the drive control unit 120 sets an initial value $absTg_i$ of the MG1 torque T_g that is caused to function as a release torque to the maximum value T_{gmax} and also sets the torque change direction to the direction of decrease in which the absolute value decreases (step S120).

[0074] The release torque is explained hereinbelow. As has already been indicated, in order to move the annular sleeve SL to the position with the stroke amount $S_{sl} = 0$ in order to switch the dog clutch mechanism 500 which is in the engagement state to the release state, it is necessary to cancel the effect of the engagement torque acting in the direction D2 depicted in FIG. 3B. The torque for canceling the effect of the engagement torque is the release torque. The release torque is equal to the MG1 torque T_g output from the first motor generator MG1 in the direction D1 depicted in FIG. 3B.

[0075] The engagement torque is equal to the sun gear shaft torque T_{es} . The sun gear shaft torque T_{es} can be obtained according to Expression (1), provided that the engine torque T_e is recognized. However, where the first motor generator MG1 is in a non-operational state, the engine torque T_e is difficult to estimate accurately. This is because where the engine 200 is compared with the first motor generator MG1, the torque

control accuracy of the engine 200 is lower than that of the first motor generator MG1.

[0076] The engine torque T_e is basically estimated on the basis of an intake air amount taken into a cylinder, a fuel injection amount, and an ignition timing by referring to a control map which has been given experimentally in advance. However, the actual
5 engine torque T_e is often affected by a large number of factors such as an intake fuel amount, a fuel injection amount, an ignition timing, an air-fuel ratio, a temperature inside a cylinder, and a cooling water temperature, and changes slightly at all times. It is difficult to determine the engine torque T_e by constantly correcting such small and irregular changes. Therefore, a certain error range occurs in the estimated value of the engine
10 torque T_e . The error range in the embodiment is defined by the upper limit value T_{max} and lower limit value T_{min} . For example, the error range can have a width of about several percent with respect to a certain estimated value.

[0077] Meanwhile, where the engagement torque in the dog clutch mechanism 500 is to be canceled by the release torque of the first motor generator MG1, a torque
15 which is equal in the absolute value to the actual sun gear shaft torque T_{es} and has the opposite sign should be applied as the release torque to the sun gear shaft SS. In view of this point, where a fixed value, which merely differs in the sign from the estimated value of the sun gear shaft torque T_{es} calculated from the estimated value of the engine torque T_e , is set as the release torque, the estimation error of the engine torque T_e can make it
20 impossible to cancel the engagement torque, and the dog clutch mechanism 500 is difficult to switch smoothly to the release state.

[0078] Accordingly, the release torque is applied so as to vary at all times between the upper limit value T_{gmax} corresponding to the upper limit value T_{max} of the estimation error range and the lower limit value T_{gmin} corresponding to the lower limit
25 value T_{min} of the estimated error range. More specifically, the release torque is applied in the direction of decreasing torque from the upper limit value T_{gmax} or in the direction of increasing torque from the lower limit value T_{gmin} . The control in which the torque is applied while being changed in a single change direction is the rocking control.

[0079] The release torque is a negative torque acting in a negative direction where

the sun gear shaft torque T_{es} is taken in the position direction. Therefore, in the strict quantitative relationship in which the sign is taken into account, the upper limit value T_{gmax} is less than the lower limit value T_{gmin} . However, since such a quantitative relationship in which the sign is taken into account can easily be misleading, in the embodiment, the release torque is explained by using the absolute value thereof on the assumption that the release torque acts in the direction opposite that of the sun gear shaft torque T_{es} .

[0080] Where it has not been determined that the accelerator depression amount T_a has increased (step S110: NO), the drive control unit 120 sets the initial value $absTg_i$ of the MG1 torque T_g , which is caused to function as the release torque, to the minimum value T_{gmin} and sets the torque change direction thereof as the direction of increasing with the increase in the absolute value (step S130).

[0081] Where step S120 or step S130 is executed, the drive control unit 120 controls the first motor generator MG1 and executes the rocking control (step S140). The stroke of the annular sleeve SL is performed by the actuator control through the clutch control unit 110 synchronously with the progress in the rocking control.

[0082] Where the rocking control is executed (started), it is determined whether or not the switching of the dog clutch mechanism 500 to the release state has ended (step S150). Where it is not determined that the switching to the release state has been completed (step S150: NO), the rocking control relating to step S140 is continued. Thus, the release torque is controlled to increase or decrease between the maximum value T_{gmax} and the minimum value T_{gmin} . Where it is determined that the switching to the release state has been completed (step S150: YES), the MG1 release control ends.

[0083] Whether or not the switching to the release state has been completed is determined on the basis of the MG1 rotation speed N_g . For example, where the MG1 rotation speed N_g is equal to or greater than a predetermined value, it is determined that the switching to the release state has been completed. Alternatively, where a rotation count number detected by a resolver which detects the rotation angle of the first motor generator MG1 is equal to or greater than a predetermined value (that is, the number of

rotations of the first motor generator MG1 is equal to or greater than the predetermined number), it is determined that the switching to the release state has been completed.

[0084] Where the vehicle is provided with a detector such as a stroke sensor which detects the stroke amount Ssl of the annular sleeve SL, it can be determined that the switching to the release state has been completed at a point of time at which the stroke amount Ssl becomes less than the aforementioned engagement stroke amount Ssllk as the stroke progresses. However, in a typical vehicle configuration which is not provided with a stroke sensor to reduce cost, the rotation state of the first motor generator MG1 is generally used for the determination. It goes without saying that in this case the timing at which it is determined that the dog clutch mechanism 500 has been switched to the release state is actually later than the timing at which the dog clutch mechanism 500 has been switched to the release state.

[0085] The effect of the MG1 release control is explained hereinbelow with reference to FIG. 6. Thus, FIG. 6 illustrates an example of the temporal transition of the operation state of each component of the hybrid vehicle 1 in the process of executing the MG1 release control.

[0086] In FIG. 6, the temporal transition of lock indication value, MG1 torque Tg, stroke amount Ssl of the annular sleeve SL, MG1 rotation speed Ng, and engine rotation speed Ne are shown in the order of description from the upper stage. The lock indication value is a control flag indicating the locking of the first motor generator MG1. Where a lock indication value Lk is set as the lock indication value, the dog clutch mechanism 500 is switched to the engagement state and the first motor generator MG1 is locked. Where a lock indication value R1 is set as the lock indication value, the dog clutch mechanism 500 is switched to the release state and the lock of the first motor generator MG1 is released. The operation control of the dog clutch mechanism 500 corresponding to the lock indication value is performed by the clutch control unit 110. The lock indication value corresponding to the operation conditions of the hybrid vehicle 1 may be set by the clutch control unit 110 or by other control unit.

[0087] In FIG. 6, the lock indication value is switched to the lock indication value

R1 at a timing t_1 , and the release of the dog clutch mechanism 500 is requested. In response to the received release request, the actuator is driven by the control performed by the clutch control unit 110, and the application of the drive force for moving the annular sleeve SL to the annular sleeve SL is started. However, at this stage, the annular sleeve
5 SL does not move in the direction of releasing the engagement thereof with the hub HB due to the effect of the engagement torque acting between the annular sleeve SL and the hub HB.

[0088] Meanwhile, at the timing t_1 at which the lock indication value is switched, the MG1 torque T_g functioning as the release torque is controlled to the upper limit value
10 T_{gmax} or the lower limit value T_{gmin} . FIG. 6 illustrates the case in which the MG1 torque T_g is controlled to the upper limit value T_{gmax} at the timing t_1 (see the solid line). Thus, FIG. 6 corresponds to the temporal transition occurring when the accelerator depression amount T_a is increased by the accelerator depression operation performed by the driver.

15 [0089] At a timing t_2 , where the MG1 torque T_g is set to the upper limit value T_{gmax} corresponding to the upper limit value of the estimation error of the engine torque T_e , the rocking control is started. The MG1 torque T_g functions as the release torque and is controlled in the direction of decreasing (direction of decreasing absolute value) at a predetermined change rate.

20 [0090] The hatched portion in the figure in the temporal transition of the MG1 torque T_g means the actual sun gear shaft torque T_{es} . The hatched portion shown in the figure has a certain width because a certain torque region that includes the exact sun gear shaft torque T_{es} is handled as the sun gear shaft torque T_{es} , and no practical problem is associated therewith. In FIG. 6, for convenience, this torque region is assumed to be
25 located in the middle between the upper limit value T_{gmax} and the lower limit value T_{gmin} . Thus, FIG. 6 represents an example corresponding to the case in which the estimated value of the engine torque T_e is substantially equal to the actual engine torque. This torque region can be also shifted toward the upper limit value T_{gmax} or the lower limit value T_{gmin} from the position depicted in the figure.

[0091] FIG. 6 depicts a state in which the release torque has reached this torque region at a timing t_3 . At this stage, the sun gear shaft torque T_{es} and the MG1 torque T_g which is the release torque act against each other, and the annular sleeve SL and the hub HB assume a torque-free state (the so-called "floating" state). As a result, the drive force of the actuator starts moving the annular sleeve SL in the direction of releasing the engagement (see an empty circle w1 in the figure).

[0092] The stroke amount S_{sl} of the annular sleeve SL increases abruptly after the timing t_3 . As a result, at a timing t_4 , the stroke amount S_{sl} is less than the S_{slk} , and the dog clutch mechanism 500 is actually switched to the release state (see an empty circle w2 in the figure).

[0093] Meanwhile, as indicate hereinabove, the timing at which it is determined that the switching of the dog clutch mechanism 500 to the release state has been completed is, in terms of control, after the actual switching completion timing. In FIG. 6, this timing is a timing t_5 at which the MG1 rotation speed N_g reaches a predetermined value (see an empty circle w3 in the figure). Therefore, the decrease of the MG1 torque T_g which is the release torque is continuous also within the period of time from the timing t_4 to the timing t_5 (see an empty circle w4 in the figure). Thus, the period of time from the timing t_2 to the timing t_5 is a rocking control period in which the rocking control is executed.

[0094] Meanwhile, since the acceleration depression operation has been performed, a required engine output P_{en} , which is an output required from the engine 200, increases. The required engine output P_{en} is determined by adding a power generation load of power for driving, as appropriate, the auxiliary devices to a basic value defined by a required drive shaft torque (the required value of the torque which is to act upon the drive shaft DS) and the drive shaft DS rotation speed (the rotation speed of the drive shaft DS). The required drive shaft torque is obtained, for example, by converting the required drive force, which is determined by the vehicle speed V and the accelerator depression amount T_a (the required value of the drive force acting upon the drive wheel DW, on the basis of the tire diameter of the drive wheel DW and the gear ratio of the reduction mechanism 400.

[0095] In FIG. 6, since the required engine output P_{en} increases, a target engine

rotation speed $Netg$ of the engine 200 changes from $Ne0$ which is a previous value to $Netg1$ at the timing $t1$. Therefore, the engine rotation speed Ne of the engine 200 starts increasing due to the control by the drive control unit 120 at or after the timing $t4$ at which the dog clutch mechanism 500 actually switches to the release state. Further, at a timing $t6$, the engine rotation speed Ne reaches the target engine rotation speed $Netg1$ (see an empty circle $w5$ in the figure).

[0096] A method for determining the initial value of the release torque without taking into account the change in the engine rotation speed Ne at or after the timing of switching to the release state is explained hereinbelow as a comparative example relating to comparison with the method for determining the initial value of the rocking torque according to the embodiment.

[0097] In the comparative example, in FIG. 6 (that is, in the case in which the accelerator depression amount Ta has increased), the initial value $absTg_i$ of the MG1 torque Tg that functions as the release torque is set to the lower limit value $Tgmin$.

[0098] The temporal transition of the MG1 torque Tg according to the comparative example is shown by a broken line in the figure. Thus, since the lower limit value $Tgmin$ is set as the initial value at the timing $t2$ and the torque change direction is set in the direction of increasing, the release torque increases at a predetermined change rate after the timing $t2$. This change rate (increase rate) is assumed to have an absolute value equal to that of the change rate (decrease rate) of the release torque according to the embodiment.

[0099] Where the engagement torque (hatched portion) which actually acts upon the pair of the engagement elements of the dog clutch mechanism 500 is positioned in the middle between the upper limit value $Tgmax$ and the lower limit value $Tgmin$ (that is, where the estimated value of the engine torque Te is correct), the release torque is in equilibrium with the engagement torque at the timing $t3$ and the stroke of the annular sleeve SL is started even in the comparative example. Further, the engagement of the annular sleeve SL and the hub HB is released at the timing $t4$.

[0100] Meanwhile, as mentioned hereinabove, the timing at which the release of

engagement is determined, in terms of control, is the timing t_5 , and the increase in the MG1 torque T_g continues within a period of time from the timing t_4 to the timing t_5 (see an empty circle w_5 in the figure).

[0101] In this case, the load of the reaction torque of the engine torque T_e acting
5 through the dog clutch mechanism 500 is switched to the load of the reaction torque created by the first motor generator MG1 at the timing t_4 at which the dog clutch mechanism 500 is switched to the release state. Since the absolute value of the MG1 torque T_g in the period of time from the timing t_4 to the timing t_5 is greater than that of the actual sun gear shaft torque T_{es} , the MG1 rotation speed N_g decreases in this period of
10 time (see an empty circle w_6 in the figure). As a result, the engine rotation speed N_e is also decreased by the differential action of the power split mechanism 300. Alternatively, rotation changes thereof are moderated.

[0102] Where the completion of switching of the dog clutch mechanism 500 to the release state is determined at the timing t_5 , the control of the engine operation point
15 corresponding to the stepless speed change mode by the drive control unit 120 is started. As a result, the MG1 torque T_g is greatly reduced so as not to interfere with the increase in the engine speed, and the MG1 rotation speed N_g increases while the reaction torque of the sun gear shaft torque T_{es} is being borne. As a result, the engine rotation speed N_e reaches the target rotation speed N_{etg1} at a timing t_7 (see an empty circle w_7 in the figure).

[0103] Thus, in the comparative example in which the initial value of the release
20 torque is determined without considering the change direction of the engine rotation speed N_e at or after the timing of switching of the dog clutch mechanism 500 to the release state, the timing at which the engine rotation speed N_e reaches a target value is delayed with respect to that in the embodiment by the period of time from the timing t_6 to the timing t_7 .
25 Further, the engine rotation speed N_e fluctuates since the engine rotation speed N_e increases after decreasing within a period of time from the timing t_4 to the timing t_5 .

[0104] By contrast, with the MG1 release control according to the embodiment, the initial value of the release torque and the change direction thereof are determined on the basis of the change direction of the accelerator depression amount T_a , the inspiration

therefor being given by the fact that the accelerator operation performed by the driver corresponds to the change direction of the engine rotation speed N_e . Thus, where the accelerator depression amount T_a increases, the release torque is controlled in the direction of decreasing by taking the upper limit value T_{gmax} as the initial value, so as to not to
5 interfere with the increase in the engine rotation speed N_e at or after the completion timing of switching of the dog clutch mechanism 500 to the release state. Conversely, where the accelerator depression amount T_a decreases, the release torque is controlled in the direction of increasing by taking the lower limit value T_{gmin} as the initial value, so as not to interfere with the decrease in the engine rotation speed N_e at or after the completion timing
10 of switching of the dog clutch mechanism 500 to the release state.

[0105] Therefore, with the MG1 release control according to the embodiment, the engine rotation speed N_e can be rapidly brought to the target engine rotation speed N_{etg} , without causing fluctuations in the engine rotation speed N_e at or after the completion timing of switching of the dog clutch mechanism 500 to the release state.

15 [0106] In FIG. 6, the case is explained in which the determination (release determination) to the effect that the switching of the dog clutch mechanism 500 to the release state has been completed is made before the release torque reaches the lower limit value T_{gmin} in the process in which the release torque is applied in the direction of decreasing by taking the upper limit value T_{gmax} as the initial value. However, the
20 release determination of the dog clutch mechanism 500 is sometimes not completed before the release torque reaches the lower limit value T_{gmin} in the process in which the release torque is applied in the direction of decreasing by taking the upper limit value T_{gmax} as the initial value. In such a case, the direction of the release torque is reversed at a point of time at which the release torque has decreased to the lower limit value T_{gmin} , and the
25 release torque is applied from the lower limit value T_{gmin} toward the upper limit value T_{gmax} by gradually changing to the direction which is opposite to the previous application direction. Thus, the rocking control is continued until the release determination of the dog clutch mechanism 500 is completed, the release torque repeatedly increasing and decreasing between the upper limit value T_{gmax} and the lower limit value T_{gmin} . The

same is true with respect to the case in which the release torque is applied in the direction of increasing by taking the lower limit value T_{gmin} as the initial value, such as the case in which the accelerator depression amount T_a is decreased when, for example, the driver performs an accelerator return operation.

5 [0107] Described in the first embodiment is the MG1 release control in which the initial value of the release torque and the change direction thereof are determined according to whether or not the accelerator depression amount T_a has increased.

 [0108] As indicated hereinabove, the accelerator depression amount T_a is a factor defining the change direction of the engine rotation speed N_e at or after the point of time at
10 which the dog clutch mechanism 500 is switched to the release state. However, in the configuration of the hybrid drive device 10, the change direction of the engine rotation speed N_e at or after the point of time at which the dog clutch mechanism 500 is switched to the release state can be determined more accurately. The second embodiment of the invention which is based on such an idea is explained hereinbelow.

15 [0109] Initially, the flow of MG1 release control according to the second embodiment is explained with reference to FIG. 7. FIG. 7 is a flowchart of the MG1 release control according to the second embodiment. In the figure, components same as those in FIG. 5 are assigned with the same reference numerals and the explanation thereof is omitted as appropriate.

20 [0110] Where the MG1 release control in FIG. 7 is started, a target operation point of the engine 200 is determined (step S210). The target operation point is in the variable continuous speed change mode after the dog clutch mechanism 500 has been switched to the release state.

 [0111] Where the target operation point of the engine 200 is determined, it is
25 determined whether or not the engine rotation speed N_e increases after the release of the dog clutch mechanism 500 (step S220) is completed. Where it is determined that the engine rotation speed N_e increases after the release of the dog clutch mechanism 500 (step S220: YES), the processing makes a transition to step S120, and the release torque is controlled to be decreased by taking the upper limit value T_{gmax} as the initial value in the

same manner as in the first embodiment. Meanwhile, where it is determined that the engine rotation speed N_e does not increase after the release of the dog clutch mechanism 500 (step S220: NO), the processing makes a transition to step S130, and the release torque is controlled to be increased by taking the lower limit value T_{gmin} as the initial value in the same manner as in the first embodiment.

[0112] The determination processing of step S220 is explained hereinbelow with reference to FIG. 8. FIG. 8 is a schematic diagram of the operation point plane of the engine 200 in the hybrid vehicle 1.

[0113] In the operation point plane shown in FIG. 8, the engine torque T_e and the engine rotation speed N_e are plotted against the ordinate and abscissa, respectively. The operation point of the engine 200 can be represented as a single coordinate point on the operation point plane. The drive control unit 120 basically sets the operation point of the engine 200 on the optimum fuel consumption operation line (shown in the figure) in the stepless switching mode. The optimum fuel consumption operation line connects the operation points in which the fuel consumption ratio of the engine 200 can be realistically minimized for each engine output P_e . The term "realistically" used herein means that operation points which have been determined as points that should not be selected with consideration for other factors, for example, a vehicle noise or vehicle vibrations, are removed.

[0114] Meanwhile, the operation line of the engine 200 in the case in which the dog clutch mechanism 500 is in the engagement state is depicted in the figure as an in-lock operation line. The engine operation point at the timing at which the execution of the MG1 release control is started is on the lock operation point shown in the figure.

[0115] In the case explained herein, an engine output P_{e3} ($P_{e3} > P_{e1}$) is requested when the engine output at the execution start timing of the MG1 release control is P_{e1} . In this case, the engine operation point at the timing at which the execution of the MG1 release control started is an operation point A (shown in the figure) in which the in-lock operation line crosses an equal output line EQP1 corresponding to the engine output P_{e1} . The engine rotation speed N_e in the operation point A is N_{e1} .

[0116] By contrast, a target engine operation point after the dog clutch mechanism 500 has been switched to the release state and the speed change mode has been switched to the stepless speed change mode is an operation point B (shown in the figure) in which the optimum fuel consumption operation line crosses an equal output line EQP3 corresponding to the engine output Pe_3 . The engine rotation speed Ne in the operation point B is Ne_2 ($Ne_2 > Ne_1$). In this case, the determination can be made that the engine rotation speed Ne increases at or after the point of time at which the dog clutch mechanism 500 is switched to the release state.

[0117] In the case explained hereinbelow, an engine output Pe_2 ($Pe_3 > Pe_2 > Pe_1$) is requested when the engine output at the execution start timing of the MG1 release control is Pe_1 . In this case, the engine operation point at the timing at which the execution of MG1 release control is started is the operation point A (shown in the figure) in which the in-lock operation line crosses the equal output line EQP1 corresponding to the engine output Pe_1 . The engine rotation speed Ne in the operation point A is Ne_1 .

[0118] By contrast, a target engine operation point after the dog clutch mechanism 500 has been switched to the release state and the speed change mode has been switched to the stepless speed change mode is an operation point C (shown in the figure) in which the optimum fuel consumption operation line crosses an equal output line EQP2 corresponding to the engine output Pe_2 . The engine rotation speed Ne in the operation point C is Ne_1 , and the engine rotation speed Ne does not change after the release. Thus, in this case, the determination can be made that the engine rotation speed Ne does not increase at or after the point of time at which the dog clutch mechanism 500 is switched to the release state.

[0119] Thus, depending on the change amount of the accelerator depression amount Ta , the engine rotation speed Ne does not change or decreases, even when the accelerator depression amount Ta increases, at or after the timing of switching of the dog clutch mechanism 500 to the release state. When the engine rotation speed Ne does not change, either one of the upper and lower limit values may be taken as the initial value of the release torque, but where the engine rotation speed decreases, since the MG1 torque Tg

acts in the direction of inhibiting the decrease in the engine rotation speed N_e , the engine rotation speed N_e does not decrease rapidly. As a result, the engine rotation speed N_e changes discontinuously and rotation fluctuations can occur when the reaction torque control through the MG1 torque T_g is started. In the embodiment, this can be avoided.

5 **[0120]** Thus, in the second embodiment, the change direction of the engine rotation speed N_e at or after the timing of switching of the dog clutch mechanism 500 to the release state can be determined more accurately than in the first embodiment. Hence, the initial value and the change direction of the release torque can be determined more precisely.

10 **[0121]** However, in the case of a small change width of the engine rotation speed N_e , including the situation explained in the second embodiment, the fluctuations of the engine rotation speed N_e at or after the timing of switching to the release state practically do not appear regardless of whether the release torque is decreased from the upper limit value T_{gmax} or increased from the lower limit value T_{gmin} . Therefore, in practice, with
15 the method for determining the initial value and change direction on the basis of the accelerator depression amount T_a , fluctuations of the engine rotation speed N_e can be advantageously suppressed.

[0122] The concept disclosed in the second embodiment may be also used in the first embodiment, and the threshold of the accelerator depression amount T_a may be set as
20 a boundary value at which the increase of the engine rotation speed N_e occurs, for each operation condition of the hybrid vehicle 1 at this point of time. In this case, where the accelerator depression amount T_a exceeds the threshold, the initial value of the release torque may be set to the upper limit value T_{gmax} . The release torque can be accurately controlled by using only the accelerator depression amount T_a as a determination criterion.

25 **[0123]** In the configurations of the above-described embodiments, the first motor generator MG1 is fixed non-rotatably by the dog clutch mechanism 500. However, practical aspects of the relationship between the engagement mechanism and differential mechanism according to the invention are not limited to such a configuration. Thus, the locking object of the dog clutch mechanism 500 can be changed by changing the

configuration of the power split mechanism serving as the differential mechanism according to the invention from that of the power split mechanism 300. The configuration and operation of such a power split mechanism 301 are described below.

[0124] Initially, the configuration of the power split mechanism 301 is explained
5 with reference to FIG. 9. FIG. 9 depicts a schematic configuration of the power split mechanism 301. In the figure, components same as those in FIG. 2 are assigned with the same reference numerals and the explanation thereof is omitted as appropriate.

[0125] In FIG. 9, the power split mechanism 301 is provided with two differential mechanisms. One differential mechanism (for convenience, referred to as the first
10 differential mechanism) has a configuration same as that of the power split mechanism 300 serving as a planetary gear mechanism of a single pinion gear type in the first embodiment. Thus, the planetary carrier C1 is coupled to the input shaft IS, the sun gear S1 is coupled to the sun gear shaft SS, and the ring gear R1 is coupled to the drive shaft DS.

[0126] Meanwhile, another differential mechanism (for convenience, referred to
15 as the second differential mechanism) is provided with a sun gear S2, a carrier C2, and a ring gear R2 mutually implementing a differential action, a pinion gear P21 meshing with the sun gear S2, and a pinion gear P22 meshing with the ring gear R2, each pinion gear being held at the carrier C2 such as to be capable of rotating in the axial line direction and revolving by the rotation of the carrier C2. Thus, the other differential mechanism is
20 configured as the so-called planetary gear mechanism of double pinion gear type.

[0127] The first and second differential mechanism are coupled to each other by coupling the ring gear R2 of the second differential mechanism to the carrier C1 of the first differential mechanism and coupling the carrier C2 of the second differential mechanism to the ring gear R1 of the first differential mechanism. The power split mechanism 301
25 becomes as a whole the so-called Ravigneaux-type planetary gear mechanism. The split mechanism 301 is provided with a total of four rotary elements, namely the sun gear S1, the carrier C1 and the ring gear R2, the ring gear R1 and the carrier C2, and the sun gear S2.

[0128] In a variation example, the sun gear S2 of the second differential

mechanism is configured to be coupled to the dog clutch mechanism 500. Thus, where the dog clutch mechanism 500 is in the engagement state, the sun gear S2 of the second differential mechanism is fixed non-rotatably. In FIG. 9, the dog clutch mechanism 500 is represented in a simplified form as compared with FIG. 2.

5 [0129] In a state in which the sun gear S2 is fixed non-rotationally, the rotation of the first motor generator MG1 is restricted in comparison with when the sun gear S2 is not fixed non-rotatably, and the MG1 rotation speed N_g is substantially determined. This is explained hereinbelow with reference to FIG. 10. FIG. 10 is an operation collinear diagram corresponding to the state in which the sun gear S2 in the power split mechanism
10 301 is locked. In the figure, components same as those in FIG. 4 are assigned with the same reference numerals and the explanation thereof is omitted as appropriate.

 [0130] In FIG. 10, the first motor generator MG1, the sun gear S2, the engine 200, and the second motor generator MG2 (primarily, the drive shaft DS) are detected, in the order of description, from the left. FIG. 10 also shows an operation collinear diagram in a
15 state in which the sun gear S2 is locked by the dog clutch mechanism 500.

 [0131] Where the sun gear S2 is locked by the dog clutch mechanism 500 when the operation point of the MG2 is an operation point m1 depicted in the figure, the operation point of the sun gear S2 is fixed at an operation point S20 corresponding to zero rotation. Therefore, the operation point of the engine 200 is determined as an operation
20 point e0' depicted in the figure.

 [0132] Meanwhile, in this state, the operation point of the sun gear S1 which is the remaining differential element of the power split mechanism 301 is also determined as an operation point gfix depicted in the figure. Thus, although the first motor generator MG1 is not directly locked by the dog clutch mechanism 500, the rotation speed thereof is
25 substantially determined.

 [0133] In the variation example, since the reaction torque of the sun gear shaft torque T_{es} is also borne through the dog clutch mechanism 500, the fixed speed change mode is realized in the same manner as in the embodiments. The control same as the MG1 release control according to the embodiments can be used.

[0134] The invention is not limited to the above-described embodiments and can be changed, as appropriate, without departing from the essence and or spirit of the invention which can be read from the claims and the entire specification. A control apparatus for a hybrid vehicle, which involves such changes, is also intended to be within
5 the technical scope of the invention.

CLAIMS:

1. A control apparatus for a hybrid vehicle, the hybrid vehicle including
 - an internal combustion engine,
 - a rotating electrical machine,
 - a drive wheel,
 - a drive shaft configured to be coupled to the drive wheel, and
 - a differential mechanism including a plurality of rotary elements performing mutually differential operations,

the internal combustion engine, the rotating electrical machine, and the drive shaft each being coupled to the plurality of rotary elements, and

an engagement mechanism including a pair of meshing engagement elements, the engagement mechanism being configured to fix non-rotatably one rotary element of the plurality of rotary elements in an engagement state in which the pair of engagement elements is engaged such that a rotation of the rotating electrical machine is restricted in comparison with when the one rotary element from among the plurality of rotary elements is not fixed non-rotatably, the control apparatus comprising:

 - an electronic control unit configured to
 - (i) control the rotating electrical machine such that when the engagement mechanism is switched from the engagement state to a release state in which the pair of engagement elements is released, a counter torque that counteracts a torque of the internal combustion engine applied to the one rotary element is output along with an increase or decrease in the counter torque;
 - (ii) control the rotating electrical machine such that the counter torque is output to be decreased when a rotation speed of the internal combustion engine increases at or after a point of time at which the engagement mechanism is switched to the release state; and
 - (iii) control the rotating electrical machine such that the counter torque is output to be increased when the rotation speed of the internal combustion engine decreases at or after the point of time at which the engagement mechanism is switched to the release state.

2. The control apparatus according to claim 1, wherein

the electronic control unit is configured to

(i) control the internal combustion engine and the rotating electrical machine such that an operation point of the internal combustion engine becomes a target operation point on a predetermined operation line when the engagement mechanism is in the release state;

(ii) control the rotating electrical machine such that the counter torque is output to be decreased when the rotation speed of the internal combustion engine increases at or after a point of time at which the engagement mechanism is switched to the release state, based on the target operation point; and

(iii) control the rotating electrical machine such that the counter torque is output to be increased when the rotation speed of the internal combustion engine decreases at or after the point of time at which the engagement mechanism is switched to the release state, based on the target operation point.

3. The control apparatus according to claim 1 or 2, wherein

the electronic control unit is configured to

(i) estimate the torque of the internal combustion engine, the torque being applied to the one rotary element, and

(ii) change the counter torque within an estimated error range including the estimated torque.

FIG. 1

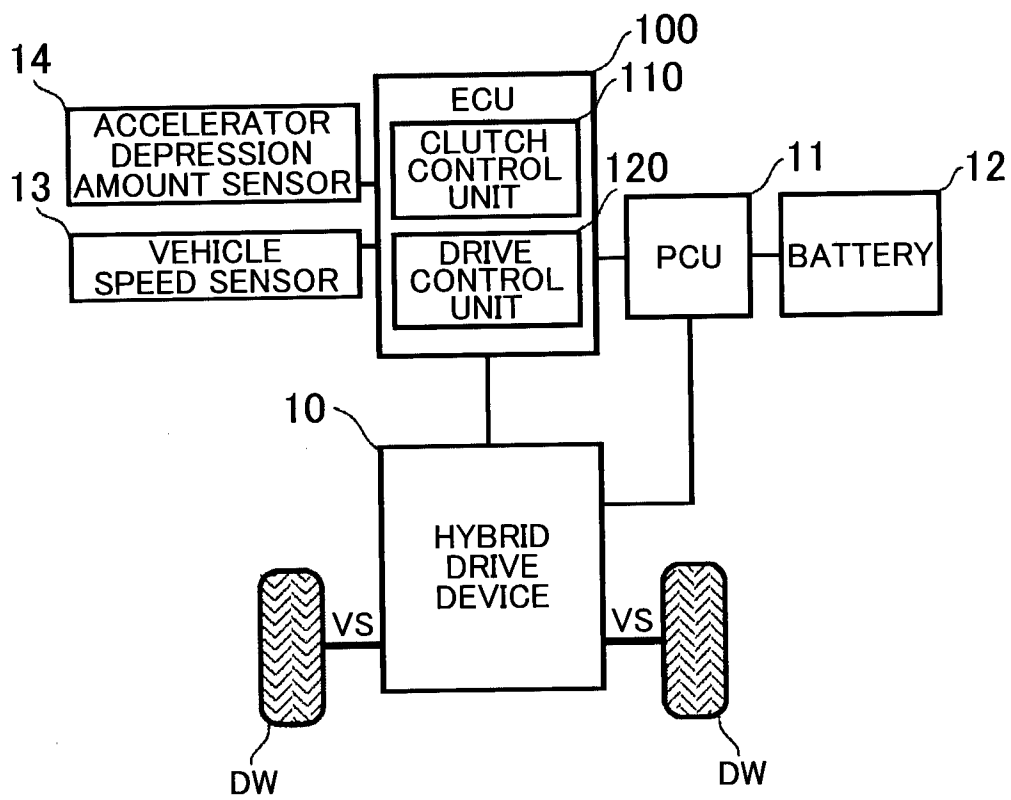


FIG. 2

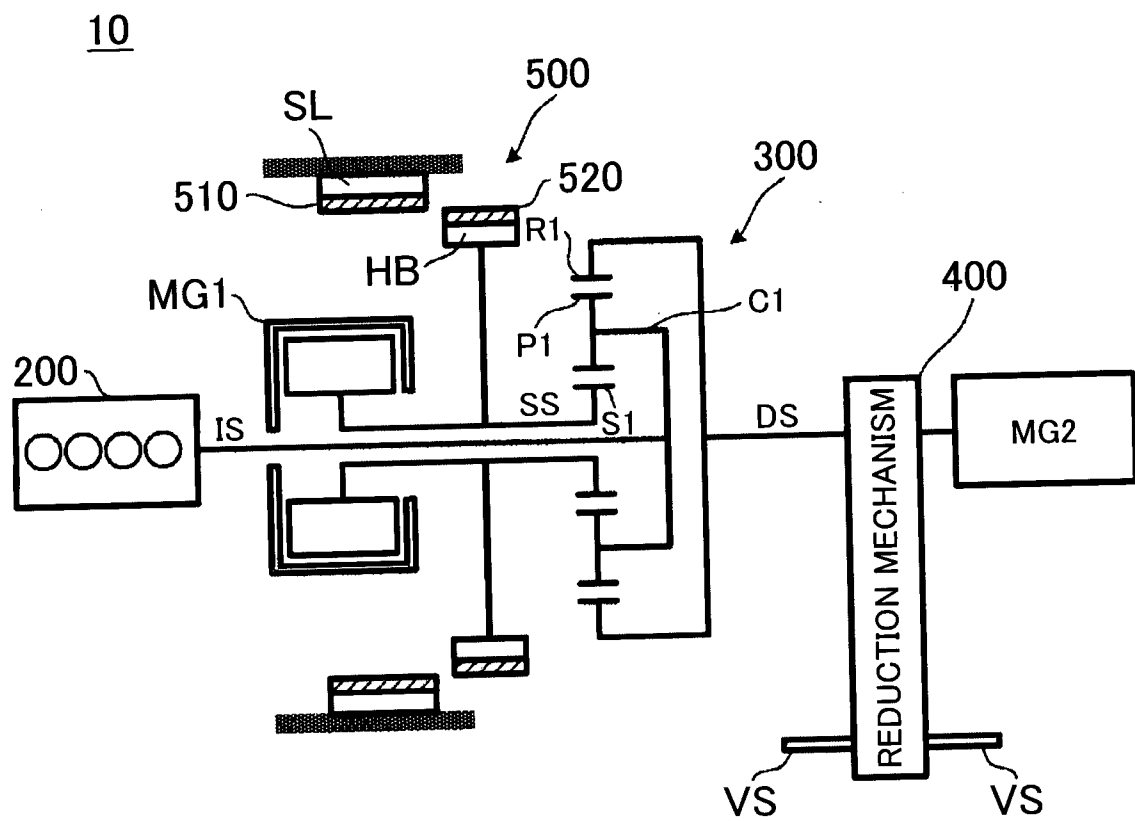
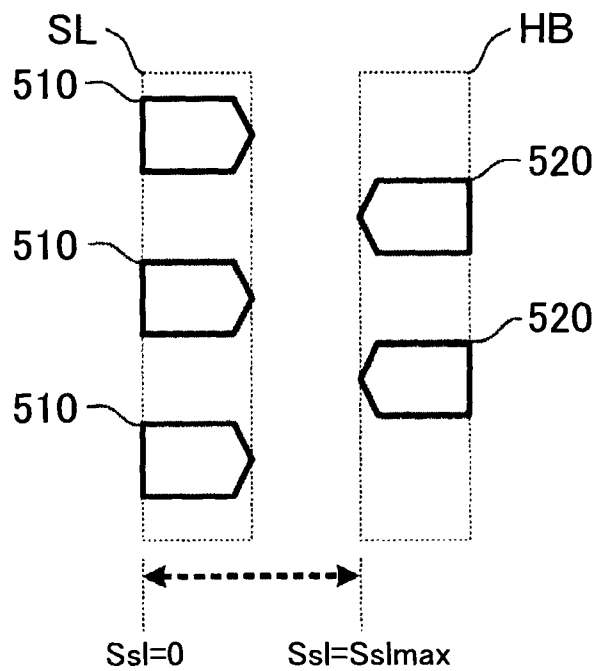
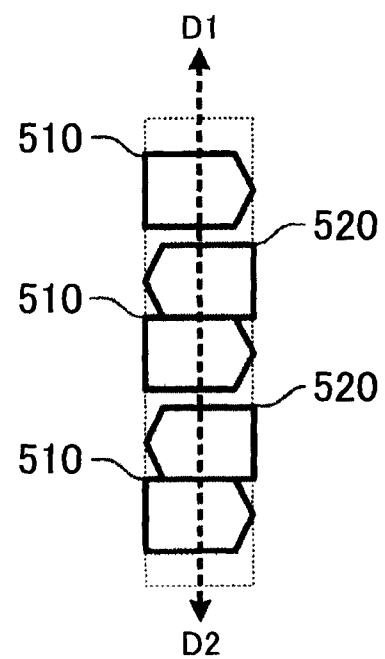


FIG. 3A



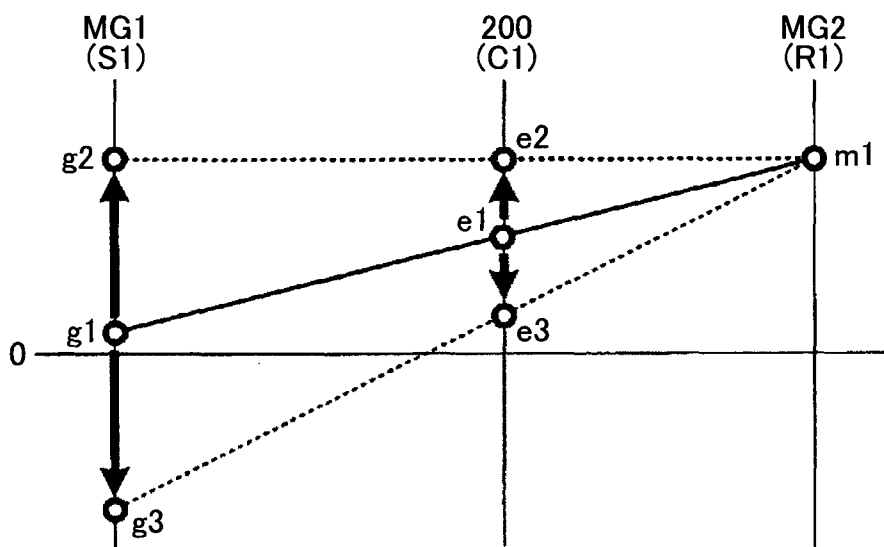
RELEASE STATE

FIG. 3B



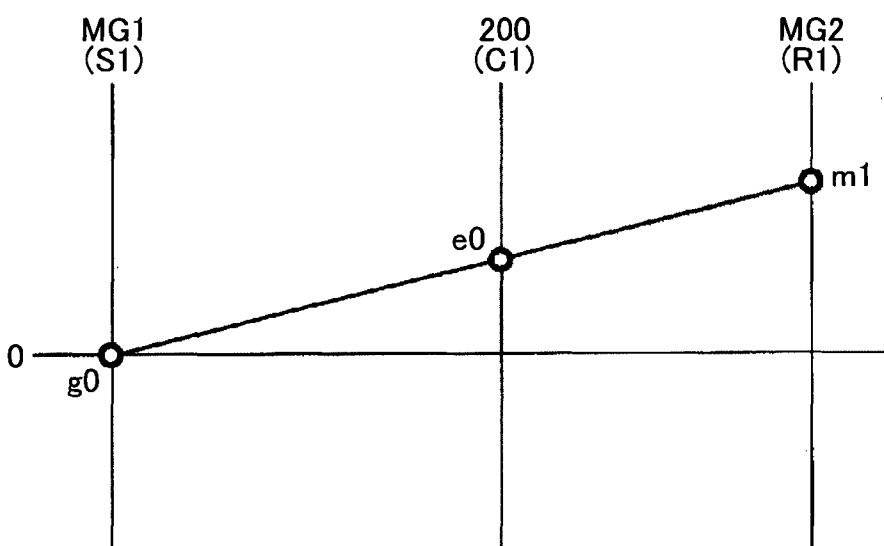
ENGAGEMENT STATE

FIG. 4A



STEPLESS SPEED CHANGE MODE

FIG. 4B



FIXED SPEED CHANGE MODE

FIG. 5

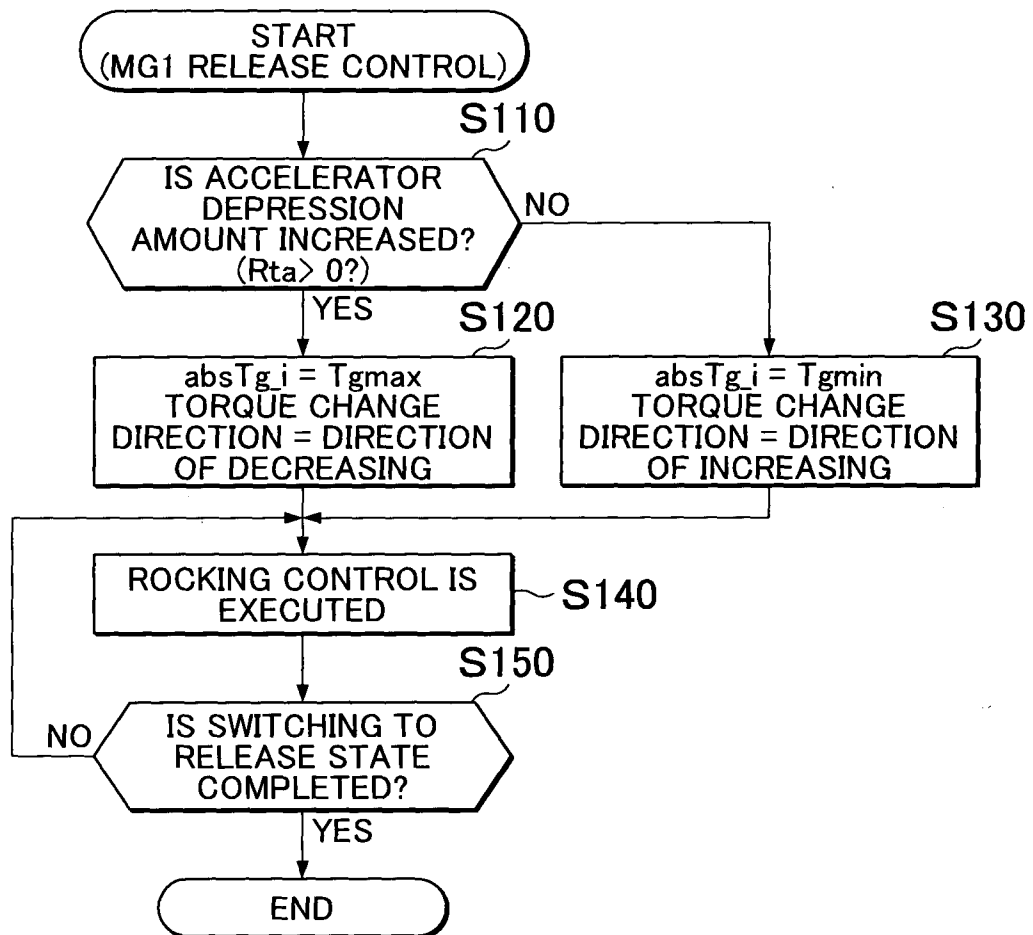


FIG. 6

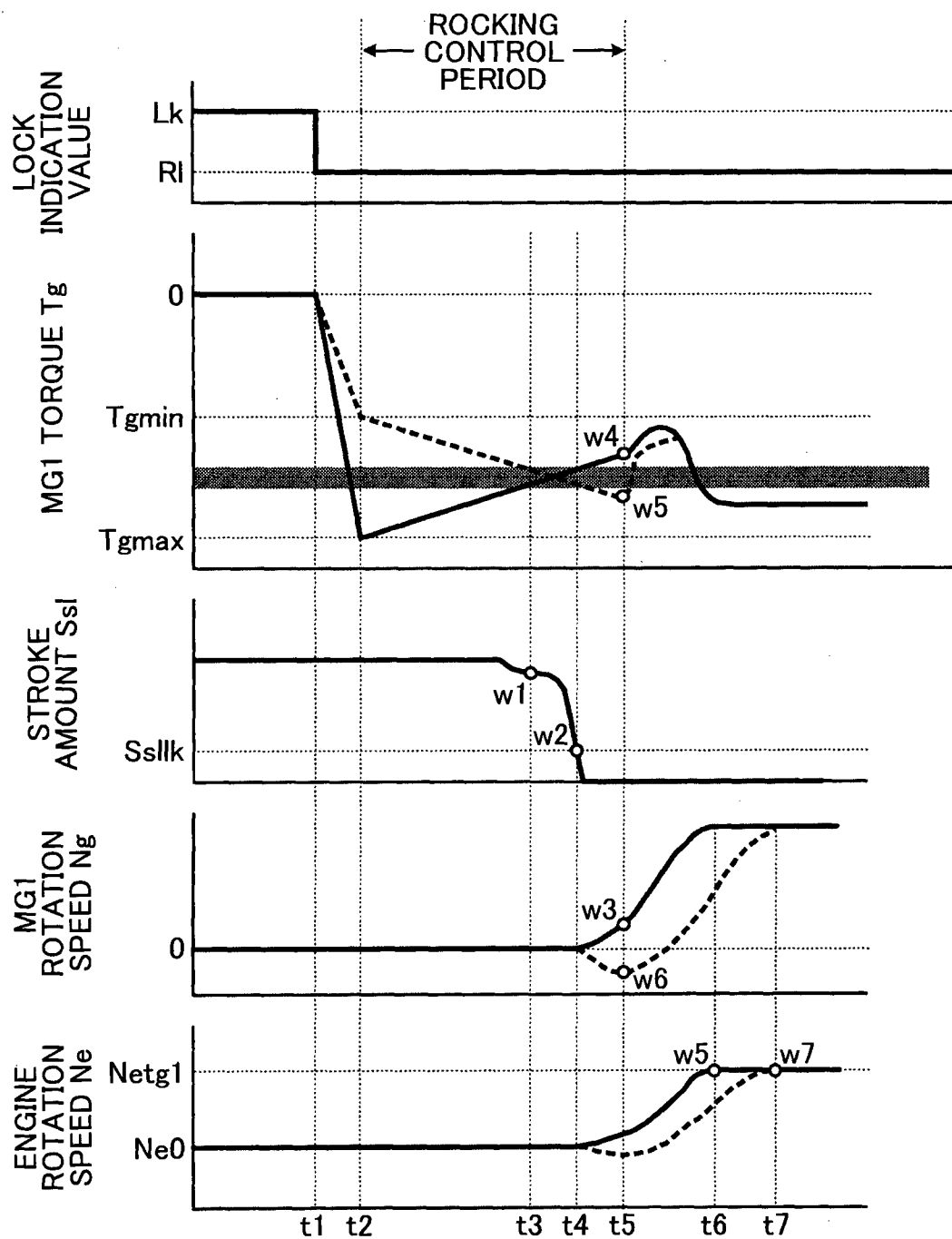


FIG. 7

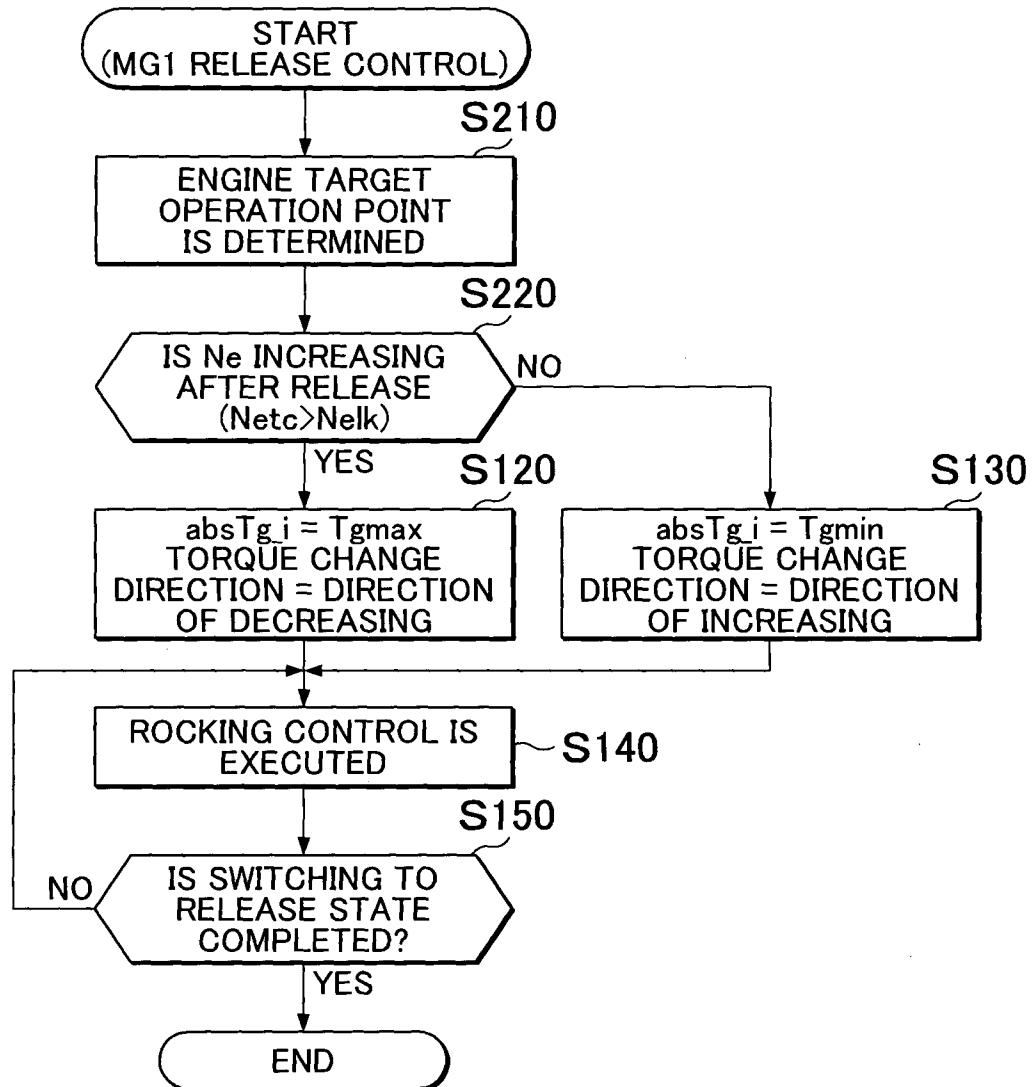


FIG. 8

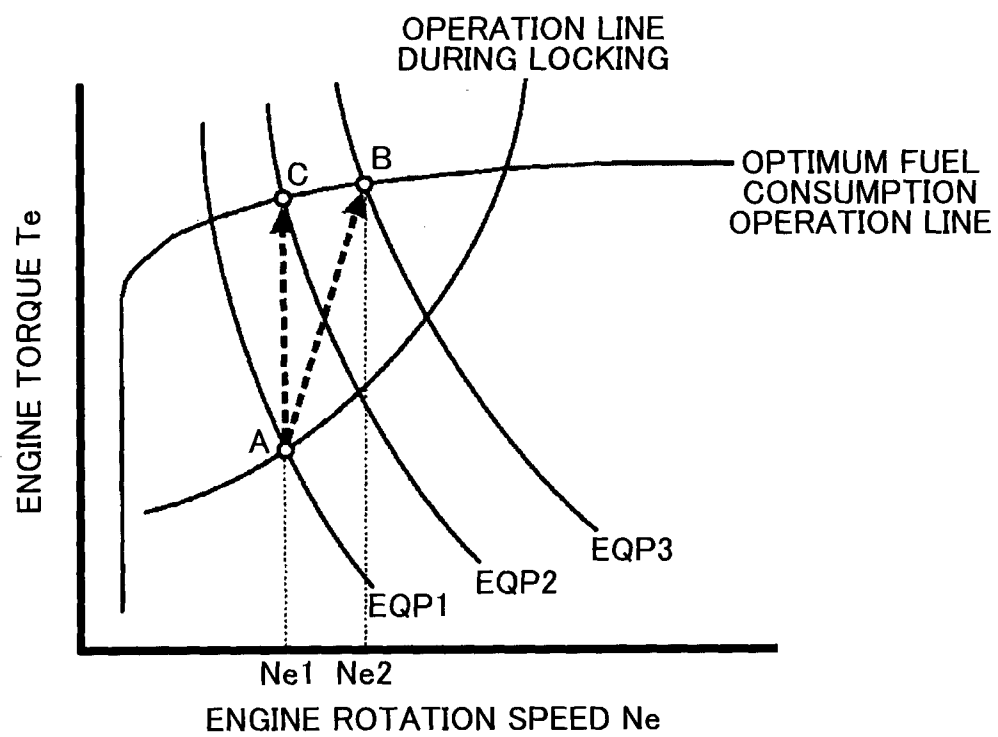


FIG. 9

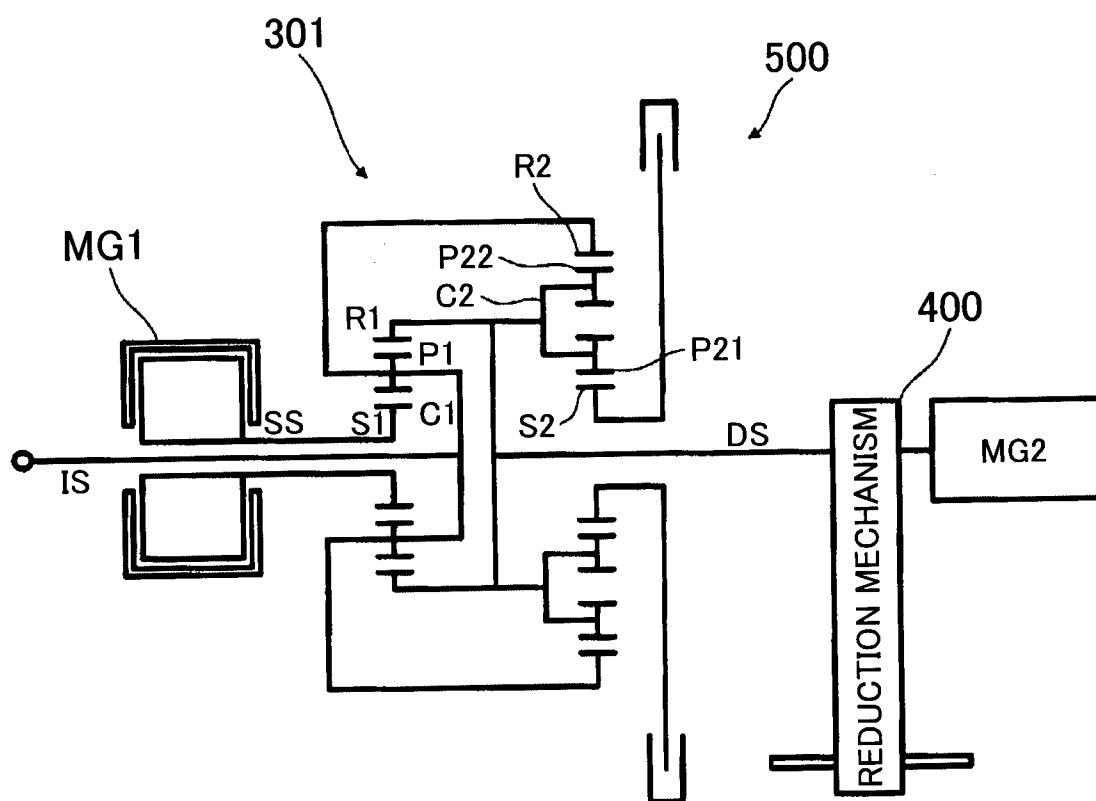
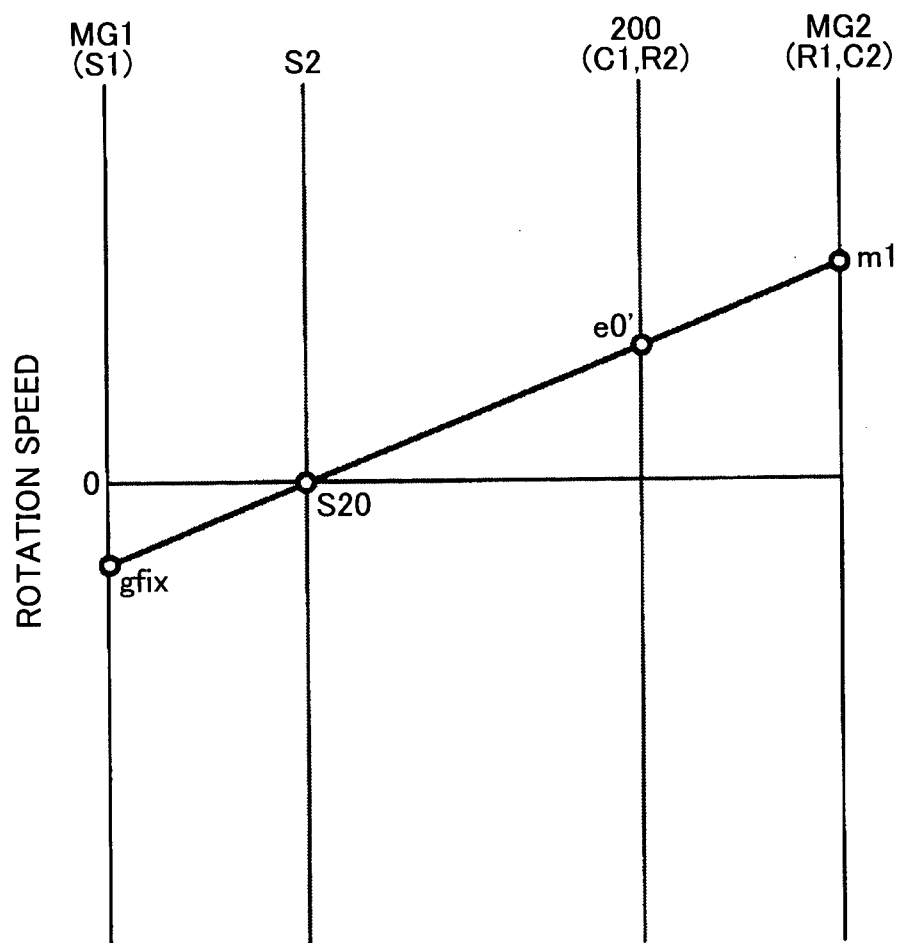


FIG. 10



INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2015/000316

A. CLASSIFICATION OF SUBJECT MATTER

INV. B60K6/445 B60W10/02 B60W10/06 B60W10/08 B60W20/00
ADD. B60K6/38

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)

B60W B60K

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)

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012/095635 A1 (KANNO YOSHIHITO [JP] ET AL) 19 April 2012 (2012-04-19) paragraphs [0006] - [0009], [0111] -----	1-3
A	US 2005/245350 A1 (TABATA ATSUSHI [JP] ET AL) 3 November 2005 (2005-11-03) paragraphs [0162], [0190] - [0193] -----	1-3
A	JP H09 156387 A (AQUEOUS RES KK; AISIN AW CO) 17 June 1997 (1997-06-17) abstract -----	1-3
A	JP 2012 051532 A (TOYOTA MOTOR CORP) 15 March 2012 (2012-03-15) abstract -----	1-3

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

☒ See patent family annex.

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Date of the actual completion of the international search

16 June 2015

Date of mailing of the international search report

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Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Nielles, Daniel

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2015/000316

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JP 2012051532 A	15-03-2012	NONE	