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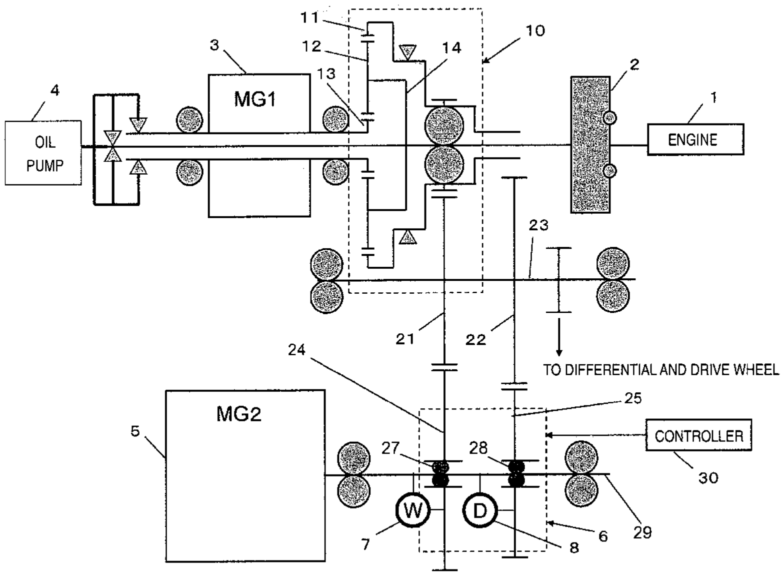

FIG. 1

(57) Abstract: A vehicle drive apparatus is basically provided with a main power source (1), a first motor/generator (3), a second motor/generator (5), a planetary gearset (10) and a step- shifting automatic transmission (6). The planetary gearset (10) is coupled to the main power source (1), the first motor/generator (3) and an output shaft (23) leading to a drive wheel. The step-shifting automatic transmission (6) connects the second motor/generator (5) to the output shaft (23) leading to the drive wheel for selectively changing an output gear ratio from the second motor/generator (5). The step-shifting automatic transmission (6) has a plurality of gear positions. The step-shifting transmission (6) includes a dog clutch (8) serving as a holding element for at least one the gear positions and a frictional holding element (7) as a holding element for at least one other of the gear positions such that the frictional holding element (7) at least transmits torque in a slipping state during a shifting operation.

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VEHICLE DRIVE APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Japanese Patent Application No. 2008-044663, filed on February 26, 2008. The entire disclosure of Japanese Patent Application No. 2008-044663 is hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention generally relates to a vehicle drive apparatus configured such that a gear ratio between a main power source and a drive train can be varied in a continuous fashion.

Background Information

[0003] Power distribution mechanism have been proposed in which at least two electric motors, a main power source (e.g., an internal combustion engine), and an output shaft are connected with at least one planetary gearset, and in which a gear ratio between the main power source and a drive wheel can be set in a continuously variable manner. For structural reasons, such a power distribution mechanism typically requires an electric motor that is large in comparison with the main power source. A transmission of a hybrid vehicle disclosed in Japanese Laid-Open Patent Publication No. 2003-127681 solves this problem by employing a mechanical transmission between one of the electric motors and the output shaft of the power distribution mechanism.

[0004] In view of the above, it will be apparent to those skilled in the art from this disclosure that there exists a need for an improved vehicle drive apparatus. This invention addresses this need in the art as well as other needs, which will become apparent to those skilled in the art from this disclosure.

SUMMARY OF THE INVENTION

[0005] It has been discovered that in the structure disclosed in Japanese Laid-Open Patent Publication No. 2003-127681, when the mechanical transmission accomplishes a gear changing function by engaging and disengaging a plurality of multiple disc clutches, a drag loss will incur in holding elements of the drive structure will incur a drag loss occurring in holding elements that are not engaged and a hydraulic pump loss will incur

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from generating and maintaining a holding pressure in holding elements that are engaged. Consequently, the total efficiency declines. Meanwhile, if dog clutches are used as holding elements that do not incur such losses, then whenever a gear change operation is executed, it is necessary to temporarily release all of the dog clutches completely at an intermediate stage in order to synchronize the rotation. Consequently, the amount of torque that can be transferred to the vehicle as a drive force is reduced.

[0006] In accordance with a first aspect, a vehicle drive apparatus is provided that basically comprises a main power source, a first motor/generator, a second motor/generator, a planetary gearset and a step-shifting automatic transmission. The planetary gearset is coupled to the main power source, the first motor/generator and an output shaft leading to a drive wheel. The step-shifting automatic transmission connects the second motor/generator to the output shaft leading to the drive wheel for selectively changing an output gear ratio from the second motor/generator. The step-shifting automatic transmission has a plurality of gear positions. The step-shifting transmission includes a dog clutch serving as a holding element for at least one the gear positions and a frictional holding element as a holding element for at least one other of the gear positions such that the frictional holding element at least transmits torque in a slipping state during a shifting operation.

[0007] These and other objects, features, aspects and advantages of the present invention will become apparent to those skilled in the art from the following detailed description, which, taken in conjunction with the annexed drawings, discloses preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Referring now to the attached drawings which form a part of this original disclosure:

[0009] Figure 1 is a schematic view of a vehicle drive apparatus in accordance with a first embodiment;

[0010] Figure 2 is a velocity diagram (lever analogy diagram) indicating the rotational speed (r.p.m.) of each rotational element on a vertical axis;

[0011] Figure 3 is a velocity diagram for a situation in which a dog clutch is engaged;

[0012] Figure 4 is a velocity diagram for a situation in which a wet clutch is engaged;

[0013] Figure 5 is a diagram for explaining the control executed when the gear ratio of the transmission is changed while a positive drive torque is being outputted from the second motor/generator;

[0014] Figure 6 is an example of a control block diagram for a case in which rotational speed feedback control is executed;

[0015] Figure 7 is a velocity diagram for a variation of the vehicle drive apparatus according to the first embodiment;

[0016] Figure 8 is a velocity diagram for explaining constituent features of a transmission of a vehicle drive apparatus in accordance with a second embodiment;

[0017] Figure 9 is a velocity diagram for explaining constituent features of a transmission of a vehicle drive apparatus in accordance with a third embodiment; and

[0018] Figure 10 is a velocity diagram for explaining constituent features of a transmission of a vehicle drive apparatus in accordance with a fourth embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] Selected embodiments of the present invention will now be explained with reference to the drawings. It will be apparent to those skilled in the art from this disclosure that the following descriptions of the embodiments of the present invention are provided for illustration only and not for the purpose of limiting the invention as defined by the appended claims and their equivalents.

FIRST EMBODIMENT

[0020] Referring initially to Figure 1, a schematic view of a vehicle drive apparatus vehicle drive apparatus is illustrated in accordance with a first embodiment. The vehicle drive apparatus is employed in a hybrid vehicle to transmit torque during shifting without causing a loss of the transmission to decline. In this hybrid vehicle, the vehicle drive apparatus includes, among other things, an engine 1, a damper 2, a first motor/generator 3, an oil pump 4, a second motor/generator 5, a transmission 6, a wet clutch 7, a dog clutch 8 and a planetary gearset 10. Output from the engine 1 is distributed to the first motor/generator 3 and to a drive output path by the planetary gearset 10. The second motor/generator 5 uses electric power generated by the first motor/generator 3 to produce an output torque. The output torque of the second motor/generator 5 is combined with the output torque of the planetary gearset 10 and delivered to a final output shaft of the drive train, thereby enabling continuously variable gear shifting.

[0021] The engine 1 serves as a main power source of the hybrid vehicle. The engine 1 is connected to the planetary gearset 10 through the damper 2. The planetary gearset 10 basically includes a ring gear 11, a plurality of planet gears 12, a sun gear 13 and a carrier 14. A crankshaft of the engine 1 is coupled to the carrier 14 of the planetary gearset 10. The carrier 14 supports the planet gears 12, which mesh with the ring gear 11 and the sun gear 13. The first motor/generator 3 is connected to the oil pump 4 and to the sun gear 13 of the planetary gearset 10. The ring gear 11 of the planetary gearset 10 is connected to an idle gear 22 and to a final output shaft 23. The idle gear 21 is connected to the second motor/generator 5 through a transmission gear 24 and the wet clutch 7. An idle gear 22 is provided on a final output shaft 23, which connected to the second motor/generator 5 through a transmission gear 25 and the dog clutch 8. The second motor/generator 5 is connected to the idle gear 21 or the idle gear 22 though the transmission 6 and thereby connected to the final output shaft 23. The torque transmitted to the final output shaft 23 is then transmitted to a pair of wheels (not shown) through a differential (not shown).

[0022] In the first embodiment, the transmission 6 is a mechanism configured to shift between two gear positions. The wet clutch 7 serves as a holding element for a gear having the smaller gear ratio. The dog clutch 8 serves as a holding element for a gear having the larger gear ratio. The wet clutch 7 is a frictional holding element that can transmit torque in a slipping state. The transmission gear 24 is supported in a freely rotatable manner on a transmission rotary shaft 29 inside the transmission 6 by a bearing 27. When the wet clutch 7 is engaged, the transmission gear 24 becomes fixedly coupled to the transmission rotary shaft 29 so that they rotate as a unit. The idle gear 22 is supported on the final output shaft 23 in a freely rotatable fashion through a bearing 28. When the dog clutch 8 is engaged, the transmission gear 24 becomes fixedly coupled to the final output shaft 29 so that they rotate as a unit. In the illustrated vehicle drive apparatus, when the dog clutch 8 is engaged, the loss efficiency can be improved in comparison with when the frictional holding element (e.g., the wet clutch 7) is engaged. Also, when the transmission 6 shifts gears, the gear shifting can be accomplished while transmitting torque from the motor/generator by putting the frictional holding element into a half engaged state.

[0023] The final output shaft 23 and other shafts are supported with respect to a vehicle body (not shown) on a plurality of bearings 26.

[0024] A controller 30 executes control of the transmission 6. The details of the control of the transmission 6 will be described later.

[0025] Figure 2 is a velocity diagram (lever analogy diagram) indicating the rotational speed (r.p.m.) of each rotational element on a vertical axis. If the rotational speeds of the rotational speeds of the engine 1 and the first motor/generator 3 are known, then the output rotational speed of the planetary gearset 10 is also known. The rotational speed of the second motor/generator 5 is reduced through the wet clutch 7 or the dog clutch 8. The rotational speed of the final output shaft 23 is reduced according to a prescribed reduction ratio by a final gear (not shown).

[0026] In the velocity diagrams, the reference letter V corresponds to the final output shaft 23. As described previously, the wet clutch 7 is a holding element for selecting the gear having the smaller reduction ratio and the dog clutch 8 is a holding element for selecting the gear having the larger reduction ratio. The controller 30 engages the wet clutch 7 in a half-clutched state when the gear ratio of the transmission 6 is being changed. As a result, a positive torque can be transmitted from the second motor/generator 5 to the final output shaft 23 through the wet clutch 7.

[0027] Figure 3 is a velocity diagram for a situation in which the dog clutch 8 is engaged. Figure 4 is a velocity diagram for a case in which the wet clutch 7 is engaged. A mode in which the dog clutch 8 is engaged is called a low mode. A mode in which the wet clutch 7 is engaged is called a high mode.

[0028] Figure 5 is a diagram for explaining the control executed when the gear ratio of the transmission 6 is changed while a positive drive torque is being outputted from the second motor/generator 5. As explained previously, the controller 30 engages the wet clutch 7 in a half-engaged state when the gear ratio of the transmission 6 is being changed. When the transmission 6 is shifted to the smaller gear ratio from a state in which the dog clutch 8 is engaged, the wet clutch 7 is engaged in a half-clutched state before the dog clutch 8 is released. Then the dog clutch 8 is released and, afterwards, the engagement force of the wet clutch 7 is increased. Meanwhile, when the transmission 6 is shifted to the larger gear ratio from a state in which the wet clutch 7 is engaged, the engagement force of the wet clutch 7 is first reduced to a half-clutched state. Then the dog clutch 8 is engaged and, afterwards, the engagement force of the wet clutch 7 is decreased to zero.

[0029] Figure 5 is shows the wet clutch 7 in a half-clutched state during shifting of the transmission 6. As indicated with arrows in Figure 5, a force acting to decrease the rotational speed of the second motor/generator 5 acts on the second motor/generator side of the wet clutch 7, and a force acting to increase the rotational speed of the final output shaft 23 acts on the final output shaft side of the wet clutch 7. Thus, when the transmission 6 is shifted, a positive torque can be transmitted from the second motor/generator 5 to the final output shaft 23 through the half-clutched wet clutch 7.

[0030] If the dog clutch 8 is used as the holding element for the gear having the smaller gear ratio and the wet clutch 7 is used as the holding element for the gear having the larger gear ratio, then during shifting of the transmission 6 a torque oriented in the opposite direction, i.e., the direction of reducing the rotational speed, will be transmitted to the final output shaft 23. When the vehicle is actually being driven, it is more important to transmit a torque acting to accelerate the vehicle than a torque acting to decelerate the vehicle. Therefore, it is preferable to use the wet clutch 7 as the holding element for the gear having the smaller gear ratio and the dog clutch 8 as the holding element for the gear having the larger gear ratio.

[0031] A method of controlling the transmission 6 during shifting (with the wet clutch 7 in a half-clutched state) will now be explained with reference to Figure 5. In the explanation, the term Tout is a final output torque target value, the term Tout' is an output torque target value of the planetary gearset 10, the term Th is a target engagement torque of the wet clutch 7, the term Gf(H) is a reduction ratio of the gear arranged to be selected with the wet clutch 7, the term Gf(L) is a reduction ratio of the gear arranged to be selected with the dog clutch 8, the term Gf(e) is a reduction ratio of the planetary gearset 10, the term N1 is a rotational speed of the first motor/generator 3, the term Ne is a rotational speed of the engine 1, and the term Nout' is an output rotational speed of the planetary gearset 10. The control executed during shifting of the transmission 6, i.e., the control executed when the rotational speed of the second motor/generator 5 is higher than the rotational speed of the final output shaft side of the wet clutch 7, comprises the processes (I) to (IV) described below.

[0032] (I) A final output torque value Tout is determined based on an accelerator pedal operation performed by the driver or the like.

[0033] (II) An apportionment of the output torque target value Tout' and the target engagement torque Th is determined. The output torque target value Tout' is determined in such a fashion that the relationship shown in the equation (1) below is satisfied and such that an output torque target value Te of the engine1 and an output torque target value T1 of the first motor/generator 3 can be achieved. The target engagement torque Th is determined using the equation (2) shown below.

$$Tout = Gf(e) \times Tout' + Gf(H) \times Th \qquad (1)$$

$$Th = (Tout - Tout' \times Gf(e))/Gf(H) \qquad (2)$$

[0034] (III) An engagement torque of the wet clutch 7 is controlled based on the target engagement torque Th of the wet clutch 7 calculated using the equation (2). For example, if the wet clutch 7 is a wet multiple disc clutch, then the engagement force of the clutch is controlled by calculating a clutch closing pressure control value P using the equation (3) shown below.

$$Th = \mu \times N \times P \qquad (3)$$

[0035] In the equation (3), the term μ is a dynamic friction coefficient of the wet clutch 7 and the term N is a number of contacting surfaces.

[0036] (IV) The output torque target value Te of the engine 1 is calculated using the equation (4) below based on the output torque target value Tout' calculated in process (II), and the output torque target value T1 of the first motor/generator 3 is calculated using the equation (5) below. The output torque of the engine 1 is then controlled based on the calculated output torque target value Te, and the output torque of the first motor/generator 3 is controlled based on the calculated output torque target value T1.

$$Te = Tout' \times (a + 1) / a \qquad (4)$$

$$T1 = Te \times 1/(a + 1) \qquad (5)$$

[0037] In the equations (4) and (5), the term a is a coefficient related to the planetary gearset and satisfies the relationship shown in the equation (6) below.

$$N1 = Ne + a \times (Ne - Nout') \qquad (6)$$

[0038] An output torque target value T2 for the second motor/generator 5 is calculated based on the target engagement torque Th of the wet clutch 7. More specifically, when the dog clutch 8 is released and the wet clutch 7 is engaged, the output torque target value T2 of the second motor/generator 5 is set to a value smaller than the target engagement torque Th by a prescribed value α. Conversely, when the wet clutch 7 is released and the dog clutch 8 is engaged, the output torque target value T2 is set to a value larger than the target engagement torque Th by a prescribed value α. The value of α does not need to be fixed and can be varied as appropriate in accordance with a control condition.

[0039] In the process (II), there are cases in which the final output torque target value Tout cannot be attained due to a restriction on the value T1, Te, or T2 or some other restriction. In such a case, the final output torque target value Tout is limited to an upper limit value Tout_max. A method of calculating the upper limit value Tout_max will now be explained.

[0040] If an output torque upper limit value of the second motor/generator 5 is expressed as T2_max, an output torque upper limit value of the engine 1 is expressed as Te_max, an output torque upper limit value of the first motor/generator 3 is expressed as T1_max, then a maximum value of the target engagement torque Th of the wet clutch 7 is equal to T2_max. The maximum value Tout'_max of the output torque target value Tout' of the planetary gearset 10 is set to the smaller of the values $a/(a + 1) \times Te\_max$ and $a \times T1\_max$ obtained from the equations (4) and (5). The upper limit value Tout_max of the final output torque target value Tout calculated with the equation (1) is expressed by the equation (7) shown below.

$$Tout\_max = Gf(e) \times Tout'\_max + Gf(H) \times T2\_max \qquad (7)$$

[0041] When the gear ratio is lowered by changing from a state in which the dog clutch 8 is engaged to a state in which the wet clutch 7 is engaged, there are cases in which the final output torque target value Tout cannot be attained due to T1, Te, T2, or another restriction. Therefore, the behavior of the vehicle can be stabilized during a change from the dog clutch 8 to the wet clutch 7 by limiting the final output torque target value Tout with the upper limit value Tout_max, thereby lowering the final output torque target value Tout, before releasing the dog clutch 8. In this way, the maximum final output torque target value Tout can be appropriately limited even when T2_max is dependent on the rotational speed N2 of the second motor/generator 5 or when Te_max is dependent on the rotational speed Ne of the engine 1.

[0042] The first motor/generator 3 and the second motor/generator 5 are connected to a common battery (not shown). Even when the output torque of the second motor/generator 5 is limited by an electric power limit of the battery, the final output torque target value Tout is limited by the upper limit value $Tout\_max$ using the method described above. For example, if a battery (not shown) that supplies electric power to the motor/generators 3 and 5 has a maximum output power Pb, then the output torque target value T2 of the second motor/generator 5 is set to satisfy the relationships expressed by the equations (8) below. In the equations (8), P1 and P2 are the output powers of the first motor/generator 3 and the second motor/generator 5, respectively.

$$-Pb < P1 + P2 < Pb, P1 = N1 \times T1, P2 = N2 \times T2 \qquad (8)$$

[0043] In such a case, the value T2 is used instead of $T2\_max$ in the equation (7) to calculate the upper limit value $Tout\_max$ and limit the final output torque target value Tout.

[0044] When the transmission switches from a state in which the dog clutch 8 is engaged to a state in which the wet clutch 7 is engaged, the target value Tout is lowered in advance before releasing the dog clutch 8. The torque transmitted by the dog clutch 8 is preferably lowered to a small value or zero. The method described above is modified in order to adjust the transmitted torque of the dog clutch 8 to zero. The final output torque target value Tout is expressed by the equation (9) below and the output torque target value T2 of the second motor/generator 5 is expressed by the equation (10), where the termTd is the transmitted torque of the dog clutch 8.

$$Tout = Gf(L) \times Td + Gf(H) \times Th + Gf(e) \times Tout' \qquad (9)$$

$$T2 = Td + Th \qquad (10)$$

[0045] The transmitted torque Td of the dog clutch 8 is decreased until it finally reaches zero by increasing the transmitted torque Th of the wet clutch 7, but do so will cause Tout to decline because of the relationship $Gf(L) > Gf(H)$. In order to avoid this problem, it is necessary to increase the output torque target value T2 and/or the output torque target value Tout', but, even so, the target value Tout will decrease if the value

Tout calculated with the equation (9) does not reach the target value Tout determined based on an accelerator operation performed by the driver or the like.

[0046] Although transmitted torque Th is gradually increased while increasing the output torque target value T2, the final output torque value Tout is limited so as to satisfy the relationship expressed in the equation (11) because $Th \leq T2\_max$.

$$Tout < Gf(H) \times T2\_max + Gf(e) \times Tout'\_max \quad (11)$$

[0047] As described above, the target value Tout is lowered before the dog clutch 8 is released, such that the transmitted torque of the dog clutch 8 is small or zero. As a result, the shock that occurs when the dog clutch 8 is released can be reduced.

[0048] Although in the preceding explanation the second motor/generator 5 is controlled based on an output torque target value T2 calculated based on the target engagement torque Th of the wet clutch 7, it is acceptable to control the second motor/generator 5 with a rotational speed feedback control. Figure 6 is an example of a control block diagram for a case in which a rotational speed feedback control is executed.

[0049] It is necessary to increase the output torque in order to increase (accelerate) the rotational speed of the second motor/generator 5, and it is necessary to decrease the output torque in order to decrease (decelerate) the rotational speed of the second motor/generator 5. The output torque target value T2 of the second motor/generator 5 used for the rotational speed feedback control can be expressed with the equation (12) shown below.

$$T2 = K\,(N2\_ref - N2\_act) \quad (12)$$

[0050] The value N2_ref is a target value of the rotational speed of the second motor/generator 5 and is set based on a target rotational speed of the gear position targeted by the shift operation of the transmission 6. The value N2_act is an actual value of the rotational speed of the second motor/generator 5 and is measured with a rotational speed sensor (not shown). K is a proportional gain for the rotational speed control.

[0051] Figure 7 is a velocity diagram for a variation of a vehicle drive apparatus according to the first embodiment. In the configuration shown in Figure 2, the output (ring gear 11) of the planetary gearset 10 is connected to the second motor/generator 5 through the transmission 6 and an idle gear. Conversely, in the configuration shown in Figure 7, the second motor/generator 5 has an independent rotary shaft that is separate from the output shaft of the planetary gearset 10. This arrangement can be achieved with, for example, a Ravigneaux planetary gear like that disclosed in Japanese Laid-Open Patent Publication No. 2005-147334. In such a case, the output shaft of the planetary gearset 10 and the second motor/generator 5 are connected differently, but the operation thereof is substantially the same. Instead of using the processes (I) to (IV) described above, the method presented in Japanese Patent Publication No. 3613273 can used as the method of controlling the drive apparatus during shifting of the transmission 6.

[0052] In a vehicle drive apparatus according to the first embodiment, at least the two motor/generators 3 and 5, the main power source 1, and the output shaft coupled to a drive train are connected with the planetary gearset 10. The motor/generator 5 is connected to the planetary gearset 10 through the step-shifting automatic transmission 6 having a plurality of gear positions. A gear ratio between the main power 1 source and the output shaft coupled to the drive train can be set in a continuously variable manner. The step-shifting transmission 6 has the dog clutch 8 serving as a holding element for at least one gear position and the wet clutch 7 (frictional holding element) arranged such that it can transmit torque in a slipping state serving as a holding element for at least one gear position. When the dog clutch 8 is engaged, it is not necessary to operate a power source, i.e., a hydraulic pump, serving to generate an engagement pressure required to engage the wet clutch 7. Thus, the amount of loss is smaller when a dog clutch is engaged than when the wet clutch 7 is engaged.

[0053] In the vehicle drive apparatus according to the first embodiment, when the step-shifting automatic transmission 6 is shifted while power is being transmitted to the final output shaft 23, the wet clutch 7 is controlled to a half-engaged state such that a positive torque can be transmitted from the motor/generator 5 to the final output shaft 23 during the shift operation of the step-shifting automatic transmission 6. As a result, the drive force imparted to the vehicle is not decreased when the step-shifting automatic transmission 6 shifts gears and the vehicle behavior exhibited during vehicle acceleration is not degraded.

[0054] In the vehicle drive apparatus according to the first embodiment, when the step-shifting automatic transmission 6 shifts while power is being transmitted from the motor/generator 5 to the final output shaft 23, the wet clutch 7 is controlled to a half-engaged state and the output torque target value Tout of the vehicle is limited based on output torque maximum values of the motor/generators 3 and 5 and an output torque maximum value of the engine 1 (main power source). As a result, the output torque target value Tout can be set appropriately based on the output torque maximum values of the motor/generators 3 and 5 and the engine 1.

[0055] In the vehicle drive apparatus according to the first embodiment, the wet clutch 7 is controlled to a half-engaged state and the output torque target value Tout of the vehicle is lowered in advance before starting a shift operation in which the dog clutch 8 is released and the wet clutch 7 is engaged. As a result, the dog clutch 8 can be released under a condition in which the transmitted torque of the dog clutch 8 is small and, thus, the shock associated with releasing the dog clutch 8 can be reduced.

SECOND EMBODIMENT

[0056] Figure 8 is a diagram for explaining constituent features of a transmission of a vehicle drive apparatus according to a second embodiment. In the vehicle drive apparatus according to the second embodiment, the transmission 6A has one wet clutch 7 and a plurality of dog clutches 81, 82,..., 8n (where n is a natural number equal to or larger than 3). In other words, the transmission 6A has (n + 1) gears of different gear ratios.

[0057] The wet clutch 7 is a holding element for the gear having the smallest reduction ratio. The dog clutch 81 is a holding element for the gear having the largest gear ratio and the dog clutch 82 is a holding element for a gear having a smaller gear ratio than the gear corresponding to the dog clutch 81. The dog clutch 8n is a holding element for the gear having the smallest gear ratio among the gears that can be selected with the dog clutches. However, the gear corresponding to the dog clutch 8n has a larger gear ratio than the gear arranged to be selected with the wet clutch 7.

[0058] The operation of switching from engagement of a dog clutch to engagement of the wet clutch 7 is the same as in the first embodiment. When the transmission 6 shifts between dog clutches corresponding to different gear ratios, the wet clutch 7 is engaged in a half-clutched state before the currently engaged dog clutch is released. After the wet clutch 7 is put into a half-clutched state, the currently engaged dog clutch is released completely before engaging the dog clutch corresponding to the targeted gear. After the dog clutch corresponding to the targeted gear is engaged, the wet clutch 7 is released.

[0059] In a vehicle drive apparatus according to the second embodiment, the transmission 6A is provided with a wet clutch 7 serving as a holding element for one gear and dog clutches serving as holding elements for two or more gears. When a dog clutch is engaged, it is not necessary to operate a power source, i.e., a hydraulic pump, to generate an engagement pressure as is required to engage the wet clutch 7. Thus, the amount of loss is smaller when a dog clutch is engaged than when the wet clutch 7 is engaged.

THIRD EMBODIMENT

[0060] Figure 9 is a diagram for explaining constituent features of a transmission of a vehicle drive apparatus according to a third embodiment. In the vehicle drive apparatus according to the third embodiment, the transmission 6B has the wet clutch 7, a plurality of dog clutches 82,..., 8n (where n is a natural number equal to or larger than 3), and a one-way clutch 90. The transmission 6B is basically the same as the transmission 6A shown in Figure 8, except that the dog clutch 81 of the transmission 6A has been replaced with the one-way clutch 90. Thus, the one-way clutch 90 serves as the holding element for the gear having the largest gear ratio of the transmission 6B.

[0061] The one-way clutch 90 engages when the rotational speed of the second motor/generator 5 is higher than the rotational speed of the final output shaft 23. Once engaged, the one-way clutch 90 disengages when the rotational speed of the second motor/generator 5 becomes lower than the rotational speed of the final output shaft 23.

[0062] In other words, when the rotational speed of the second motor/generator 5 rises and becomes higher than the rotational speed of the final output shaft 23, the one-way clutch 90 engages such that output torque from the second motor/generator 5 is transmitted to the final output shaft 23. By using the one-way clutch 90 instead of a dog clutch as the holding element for the gear having the largest gear ratio, the loss efficiency can be improved because the loss that would occur when operating the dog clutch is avoided.

[0063] Also, when the one-way clutch 90 engages such that the output torque from the second motor/generator 5 is transmitted to the final output shaft 23, the transmission 6B is automatically put into a state in which drive power is transmitted using the gear having the largest reduction ratio. Consequently, the drive force shock that occurs due to a rotational speed difference when a dog clutch is engaged can be reduced.

FOURTH EMBODIMENT

[0064] Figure 10 is a diagram for explaining constituent features of a transmission of a vehicle drive apparatus according to a fourth embodiment. In the vehicle drive apparatus according to the fourth embodiment, the transmission 6C has the wet clutch 7, a plurality of dog clutches 81, 82,..., 8n (where n is a natural number equal to or larger than 3), and a one-way clutch 90. The one-way clutch 90 is connected in parallel with the dog clutch 81, which is a holding element for the gear having the largest gear ratio.

[0065] When only a one-way clutch 90 is provided as a holding element for the gear having the largest gear ratio as in the third embodiment, it is not possible to connect the one-way clutch 90 while rotating the second motor/generator 5 in a reverse direction. Thus, it is not possible to rotate the final output shaft 23 in reverse through the one-way clutch 90 so as to back the vehicle.

[0066] In the vehicle drive apparatus according to the fourth embodiment, the dog clutch 81 and the one-way clutch 90 are provided in a parallel arrangement as holding elements for the gear having the largest gear ratio. When the gear having the largest reduction ratio in the transmission 6C selected, the one-way clutch 90 is engaged when the second motor/generator 5 is rotated in the positive direction (forward direction) and the dog clutch 81 is engaged when the second motor/generator is rotated in the reverse direction. As a result, when the second motor/generator 5 transmits a positive drive torque or force, the loss associated with connecting a clutch can be reduced by connecting the one-way clutch 90. Meanwhile, when the second motor/generator 5 transmits a negative drive force, the vehicle can be driven in reverse (backed) by connecting the dog clutch 81.

[0067] In the vehicle drive apparatus according to the fourth embodiment, the dog clutch 81 is provided as a holding element for the gear having the largest gear ratio and the one-way clutch 90 is provided in parallel with the dog clutch 81. As a result, the same effects as the vehicle drive apparatus according to the third embodiment can be obtained and, additionally, the ability to transmit a negative drive force from the second motor/generator 5 can be obtained.

GENERAL INTERPRETATION OF TERMS

[0068] In understanding the scope of the present invention, the term “comprising” and its derivatives, as used herein, are intended to be open ended terms that specify the presence of the stated features, elements, components, groups, integers, and/or steps, but do not exclude the presence of other unstated features, elements, components, groups, integers and/or steps. The foregoing also applies to words having similar meanings such as the terms, "including", "having" and their derivatives. Also, the terms "part," "section," "portion," "member" or "element" when used in the singular can have the dual meaning of a single part or a plurality of parts.

[0069] While only selected embodiments have been chosen to illustrate the present invention, it will be apparent to those skilled in the art from this disclosure that various changes and modifications can be made herein without departing from the scope of the invention as defined in the appended claims. For example, although in the embodiments a wet clutch is used as the frictional holding element, an electromagnetic clutch or any other type of holding element can be used so long as it can transmit torque in a slipping state. In addition in Figures 8 to 10, the transmission is depicted as having (n + 1) gears of different gear ratios (where n is a natural number equal to or larger than 3). However, it is acceptable for the value of n to be 2 (n = 2) and, in the configurations shown in Figures 9 and 10, it is acceptable for the transmission to have two gears. When the transmission shown in Figure 9 is configured as a two-gear transmission, the one-way clutch 90 is provided with respect to the gear having the largest gear ratio and the wet clutch 7 is provided with respect to the gear having the smallest gear ratio. Also in Figure 6, a proportional control is presented as an example of a rotational speed feedback control. However, it is also acceptable to use a PI control (combination of a proportional control and an integral control) or a PID control (combination of a proportional control, an integral control, and a derivative control).

[0070] Moreover, components that are shown directly connected or contacting each other can have intermediate structures disposed between them, unless otherwise indicated. The functions of one element can be performed by two, and vice versa. The structures and functions of one embodiment can be adopted in another embodiment. It is not necessary for all advantages to be present in a particular embodiment at the same time. Every feature which is unique from the prior art, alone or in combination with other features, also should be considered a separate description of further inventions by the applicant, including the structural and/or functional concepts embodied by such feature(s). Thus, the foregoing descriptions of the embodiments according to the present invention are provided for illustration only, and not for the purpose of limiting the invention as defined by the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. A vehicle drive apparatus comprising:

a main power source;

a first motor/generator;

a second motor/generator;

a planetary gearset operatively coupled to the main power source, the first motor/generator and an output shaft leading to a drive wheel; and

a step-shifting automatic transmission connecting the second motor/generator to the output shaft leading to the drive wheel for selectively changing an output gear ratio from the second motor/generator, the step-shifting automatic transmission having a plurality of gear positions;

the step-shifting transmission including a dog clutch serving as a holding element for at least one the gear positions and a frictional holding element as a holding element for at least one other of the gear positions such that the frictional holding element at least transmits torque in a slipping state during a shifting operation.

2. The vehicle drive apparatus recited in claim 1, wherein

the dog clutch is engaged to establish the one of the gear positions, which has a larger gear ratio of the gear positions with respect to the other of the gear positions being established by engagement of the frictional holding element.

3. The vehicle drive apparatus recited in claim 2, further comprising:

a one-way clutch that is arranged in parallel with the dog clutch and configured to engage when a rotational speed of the second motor/generator is higher than a rotational speed of the output shaft leading to the drive wheel.

4. The vehicle drive apparatus recited in claim 1, wherein
the frictional holding element is engaged to establish the other of the gear positions, which has a smaller gear ratio of the gear positions with respect to the one of the gear positions being established by engagement of the dog clutch.

5. The vehicle drive apparatus recited in claim 1, wherein
the step-shifting automatic transmission has at least three of the gear positions, with the dog clutch serving being engaged to establish the one of the gear positions which is other than a gear position having a largest gear ratio and a gear position having a smallest gear ratio.

6. The vehicle drive apparatus recited in claim 1, further comprising
a control device operatively coupled to the frictional holding element to selectively control the frictional holding element to a half-engaged state when the step-shifting automatic transmission is shifted under a condition in which power is transmitted from the second motor/generator to the output shaft leading to the drive wheel.

7. The vehicle drive apparatus recited in claim 6, wherein
the control device is further configured to determine an output torque target value of the second motor/generator based on a gear ratio of the frictional holding element and an output torque target value for the output shaft leading to the drive wheel.

8. The vehicle drive apparatus recited in claim 6, wherein
the control device is further configured to lower an output torque target value of the output shaft leading to the drive wheel in advance when the step-shifting automatic transmission is shifted while power is being transmitted from the second motor/generator to the output shaft leading to the drive wheel.

9. The vehicle drive apparatus recited in claim 6, wherein

the control device is further configured to limit an output torque target value of the output shaft leading to the drive wheel based on an output torque maximum value of at least the first and second motor/generators and an output torque maximum value of the main power source.

10. The vehicle drive apparatus recited in claim 6, wherein

the control device is further configured to execute a rotational speed feedback control of at least one of the first and second motor/generators.

11. The vehicle drive apparatus recited in claim 1, wherein

the dog clutch is engaged to establish the one of the gear positions, which has a largest gear ratio of the gear positions.

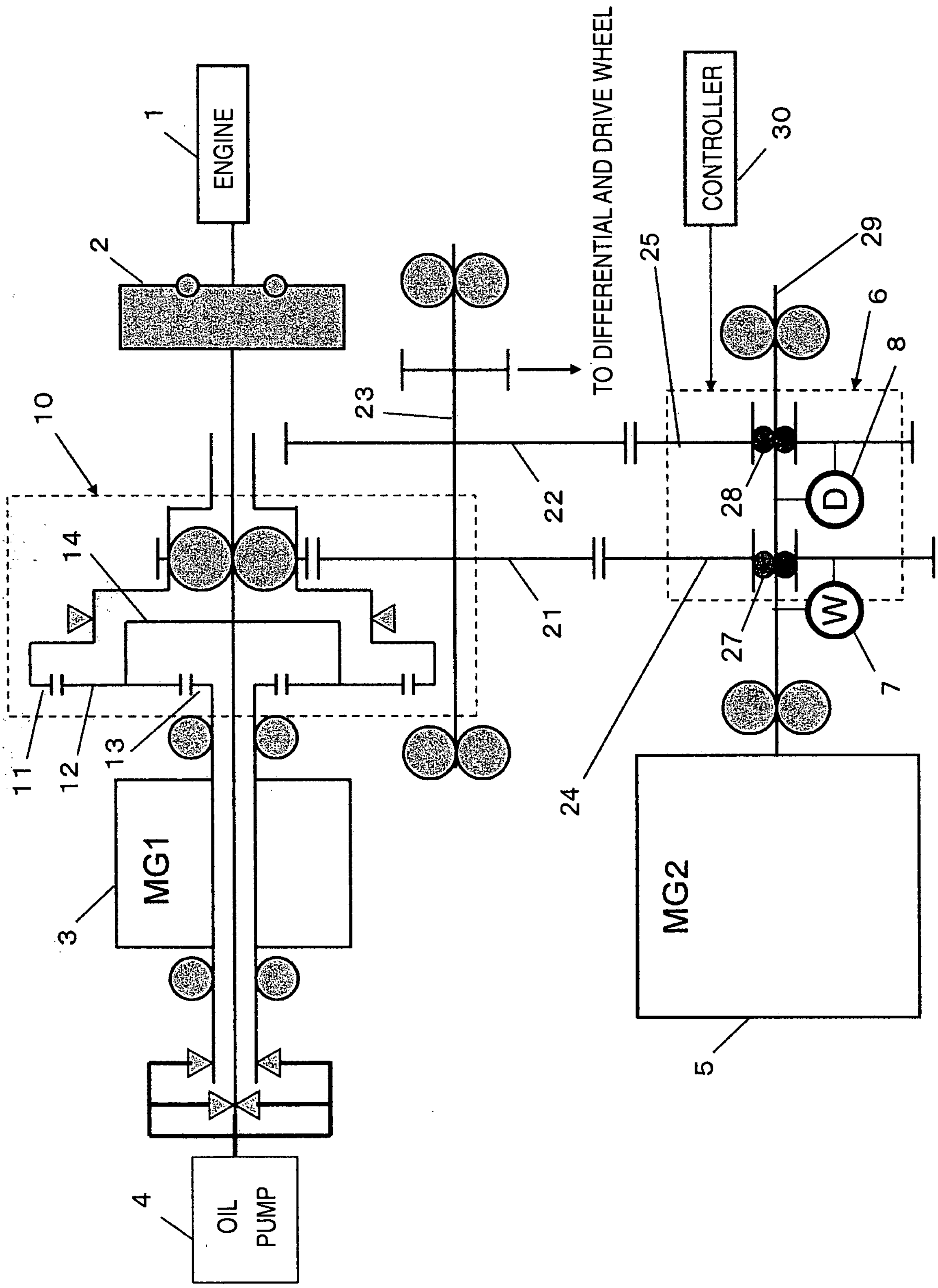
ENGINE
TO DIFFERENTIAL AND DRIVE WHEEL
CONTROLLER
MG1
MG2
OIL PUMP
D
W
1
2
3
4
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FIG. 1

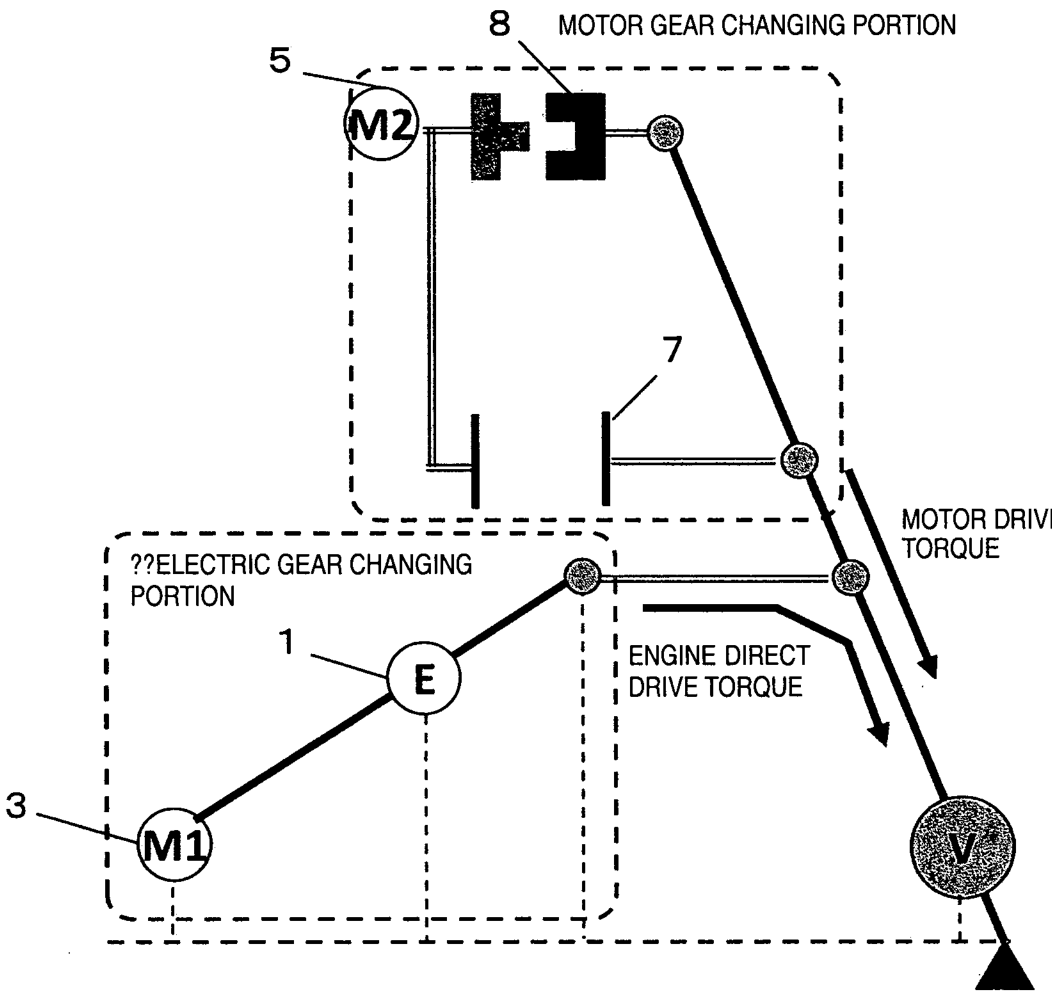

8
MOTOR GEAR CHANGING PORTION
5
M2
7
MOTOR DRIVE
TORQUE
??ELECTRIC GEAR CHANGING
PORTION
1
E
ENGINE DIRECT
DRIVE TORQUE
3
M1
V

FIG. 2

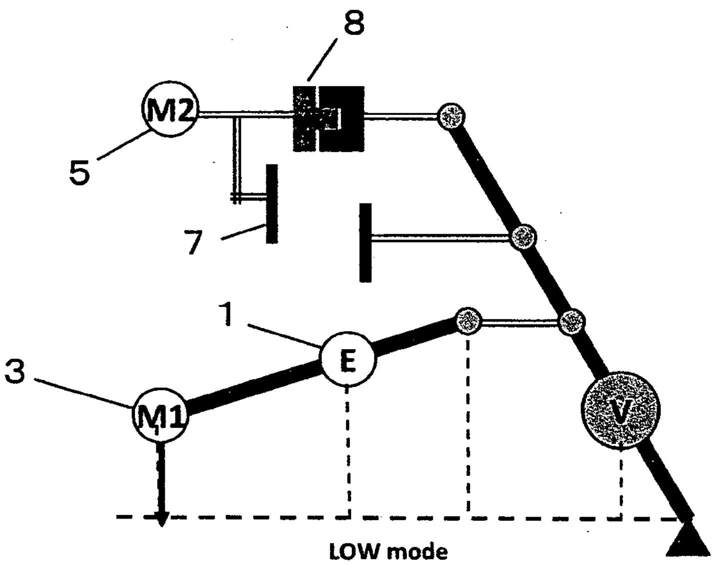


FIG. 3

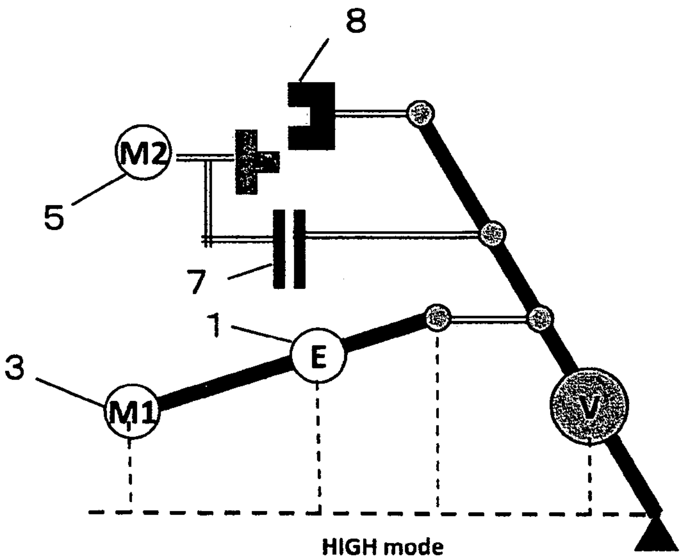
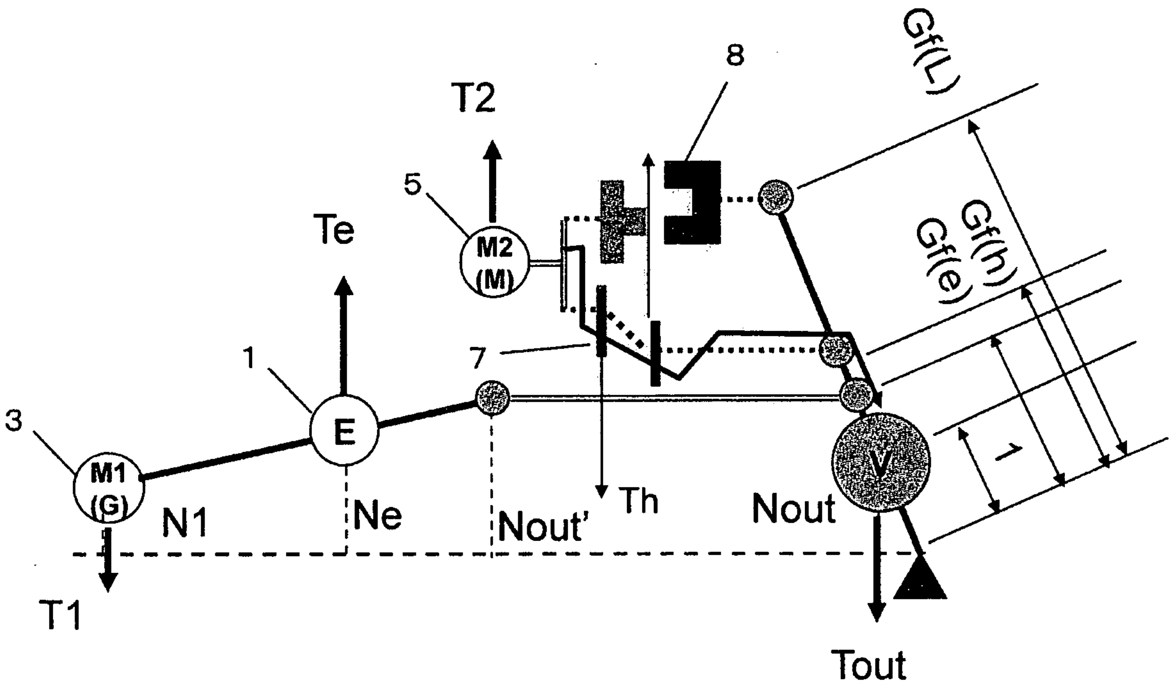
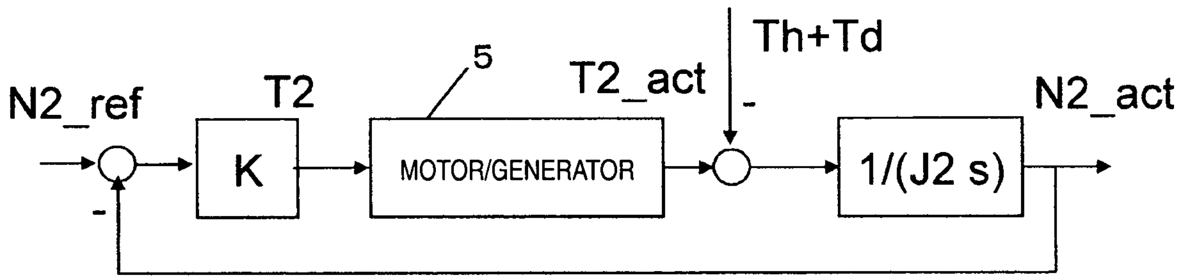


FIG. 4



Gf(L)
8
T2
5
M2
(M)
Te
Gf(h)
Gf(e)
1
7
3
E
M1
(G)
N1
Ne
Nout'
Th
Nout
V
1
T1
Tout

FIG. 5



Th+Td
5
T2_act
N2_ref
T2
N2_act
K
MOTOR/GENERATOR
1/(J2 s)
-
-

FIG. 6

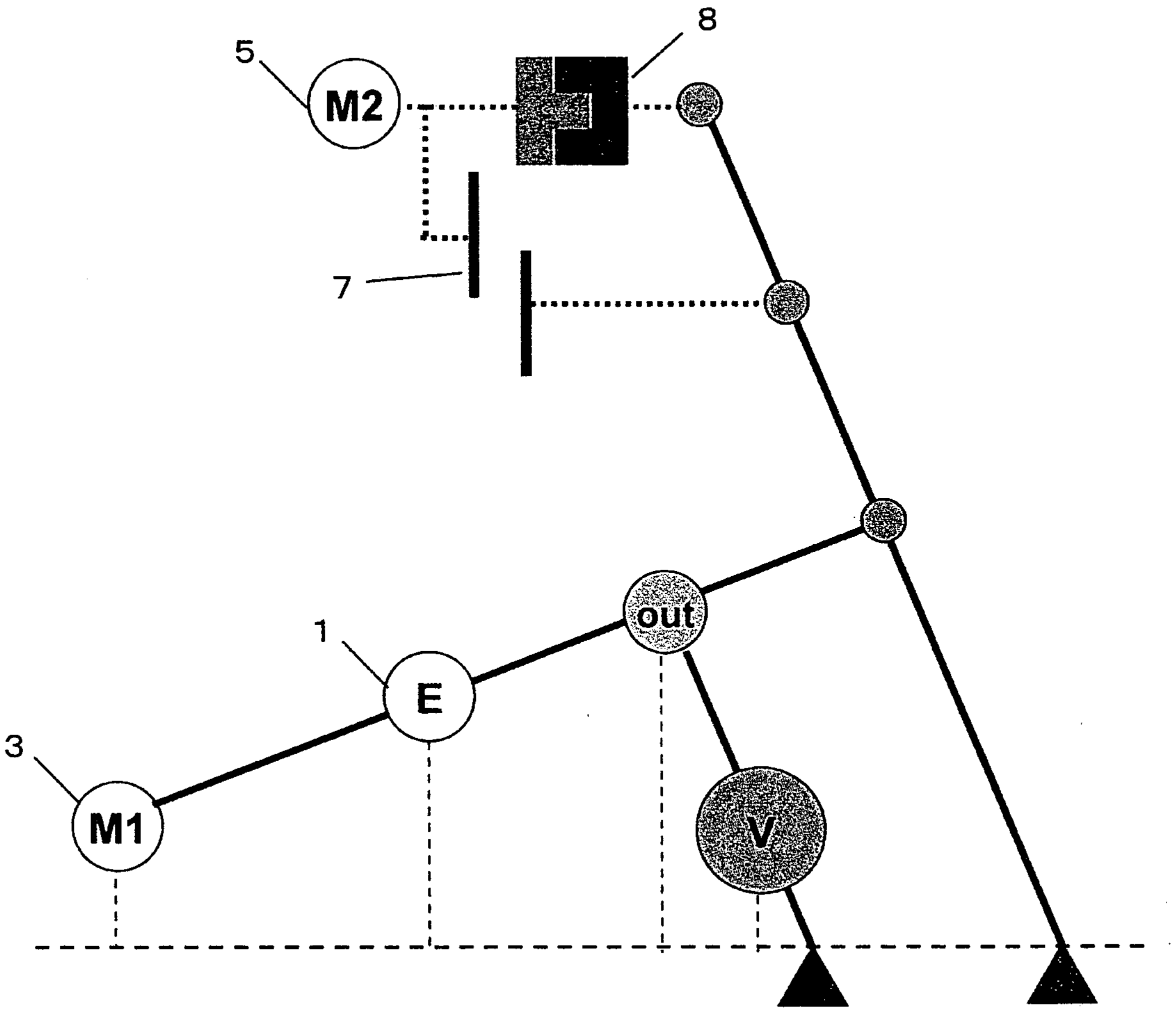


FIG. 7

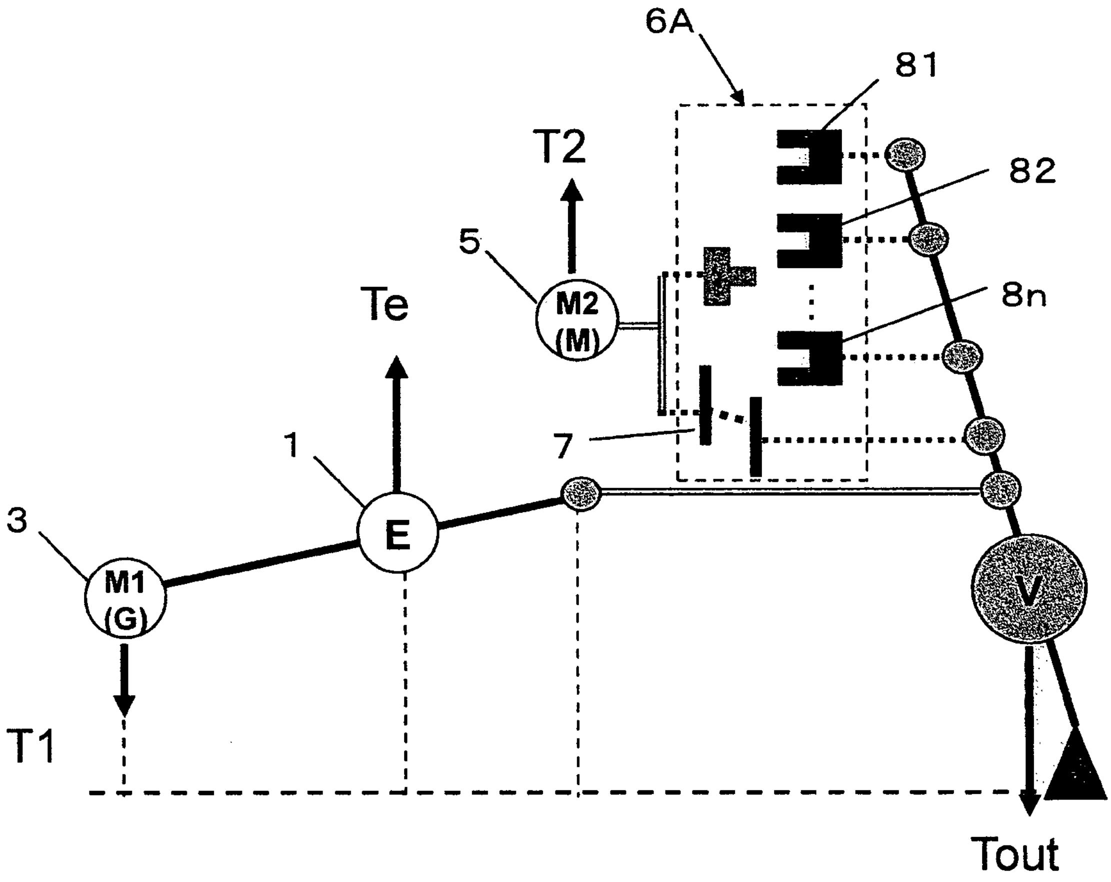


FIG. 8

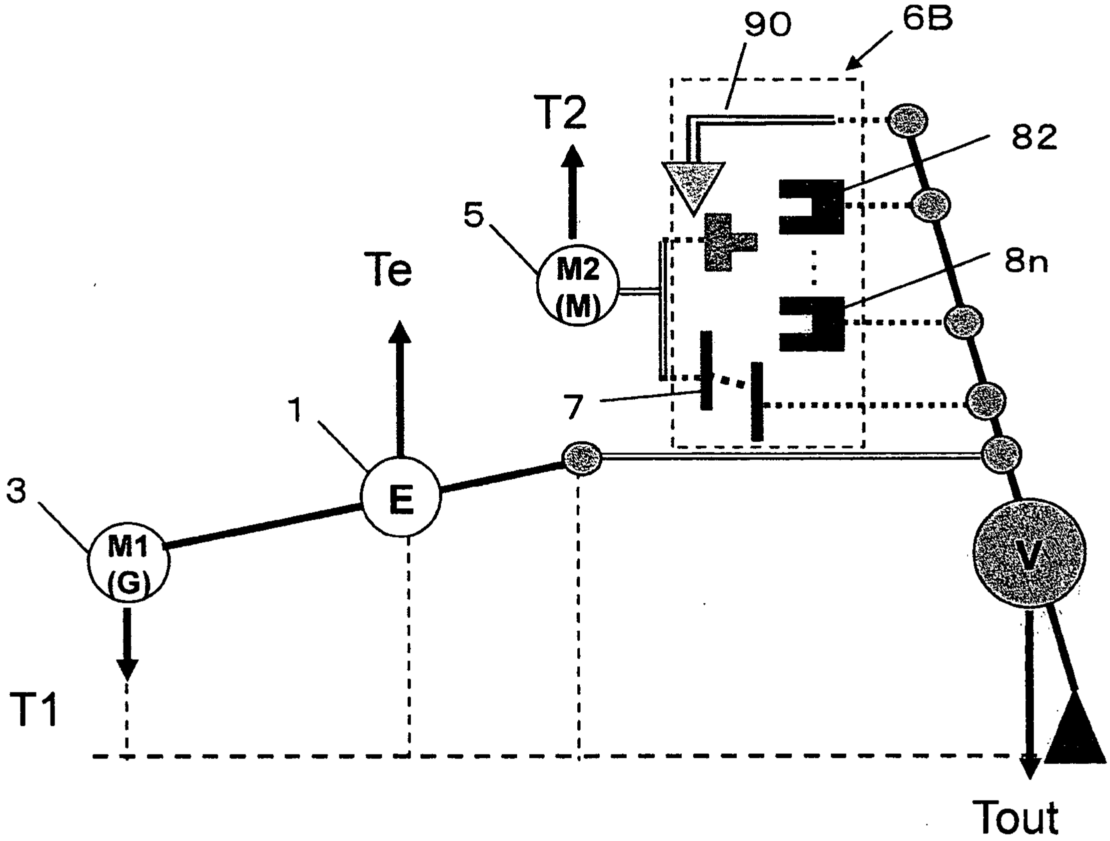


FIG. 9

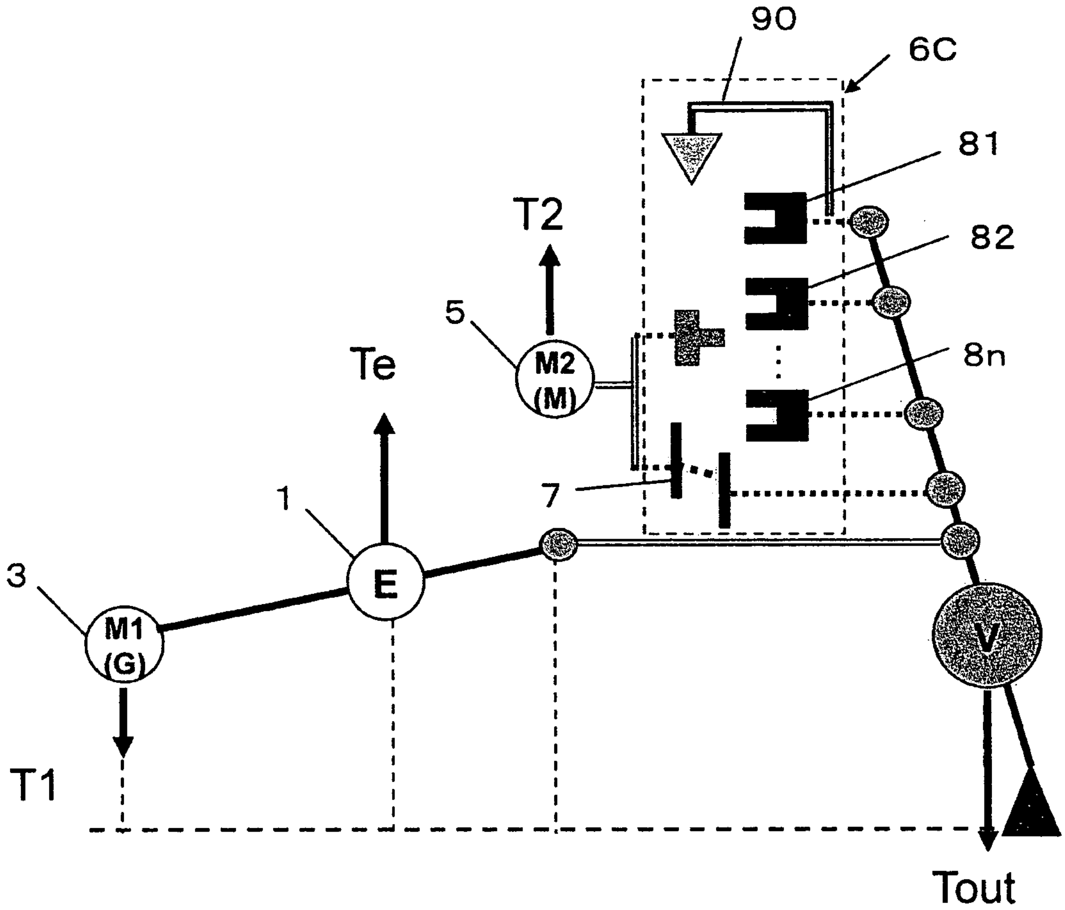


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2009/000281

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. See extra sheet

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)

Int.Cl. B60K6/365, B60K6/445, B60K6/547, B60L11/14, B60W10/08, B60W10/10, B60W20/00, F16H61/04, F16H61/684

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2009
Registered utility model specifications of Japan 1996-2009
Published registered utility model applications of Japan 1994-2009

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2003-127681 A (TOYOTA JIDOSHA KABUSHIKI KAISHA) 2003.05.08, paragraph 0026, Fig 6 & US 2003/0078134 A1 & DE 60214104 T2 & CA 2406817 A1 & ES 2269583 T3 & CN 1413855 A & KR 2003-0033971 A	1-11
Y	JP 2000-301959 A (HITACHI, LTD.) 2000.10.31, claims 1,2, paragraph 0036, Fig 4 & US 6341541 B1 & DE 10019597 A1	1-11
Y	JP 2000-6676 A (HONDA MOTOR CO., LTD.) 2000.01.11, paragraph 0033, Figs 4,5 (Family:none)	3,5

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12.05.2009	26.05.2009

Name and mailing address of the ISA/JP
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Tsuda, Shingo
Telephone No. +81-3-3581-1101 Ext. 3328

CLASSIFICATION OF SUBJECT MATTER

B60K6/365(2007.10)i, B60K6/445(2007.10)i, B60K6/547(2007.10)i,
B60L11/14(2006.01)i, B60W10/08(2006.01)i, B60W10/10(2006.01)i,
B60W20/00(2006.01)i, F16H61/04(2006.01)i, F16H61/684(2006.01)n