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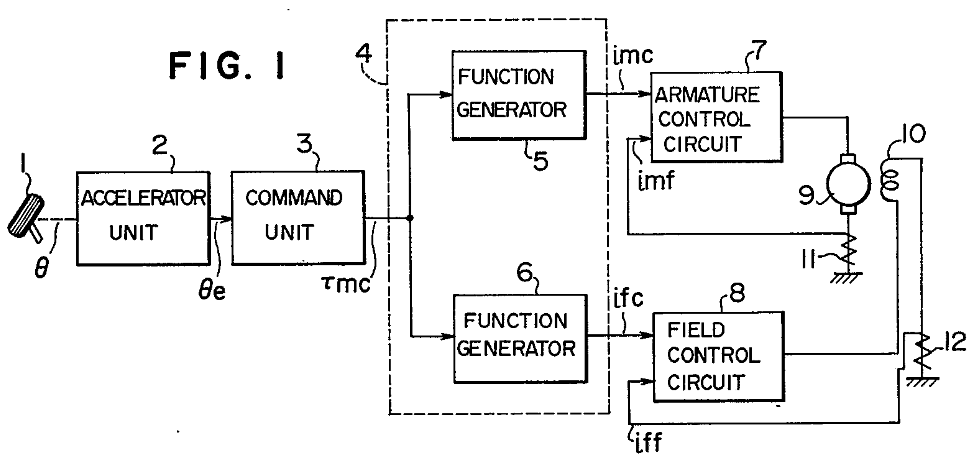
(54) Electric vehicle control device

(57) A control device for an electric vehicle provided with a shunt motor 9, 10 includes a pattern generating means 4 for storing, as patterns, armature and field currents capable of generating a motor output torque with a minimum loss in the driving system of the vehicle. The pattern generating means delivers an armature current command and a field current command, dependent on the position of an accelerator 1, that are used by an armature control circuit 7 for supplying the shunt motor with an armature current corresponding to the armature current command, and a field control circuit 8 for supplying the shunt motor with a field current corresponding to the field current command.

The pattern generating means may be function generators (e.g. as Fig. 4, not shown) or include a microprocessor, with current limiting according to sensed controller temperature or motor supply (a battery) voltage. In an embodiment armature current is controlled by thyristors, and field current by a transistor, and the currents regulated to their respective command values.

FIG. 1



GB 2 040 085 A

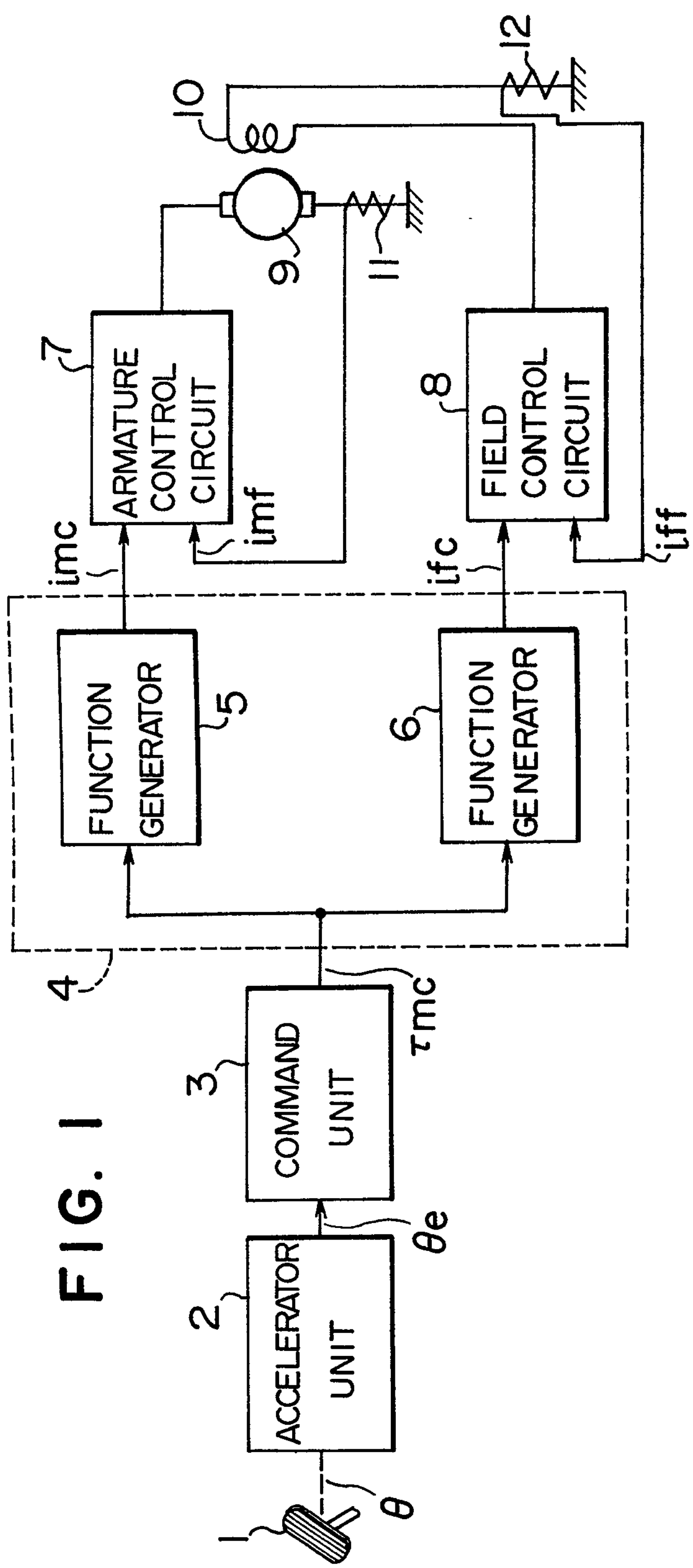


FIG. 1

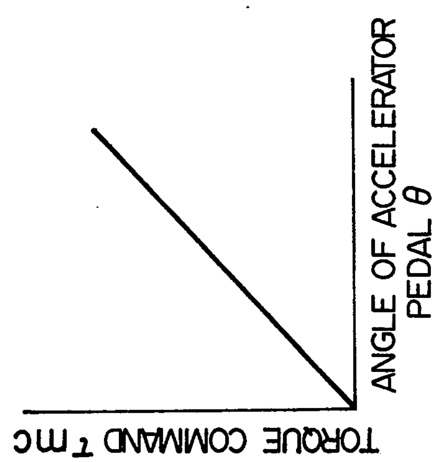


FIG. 2

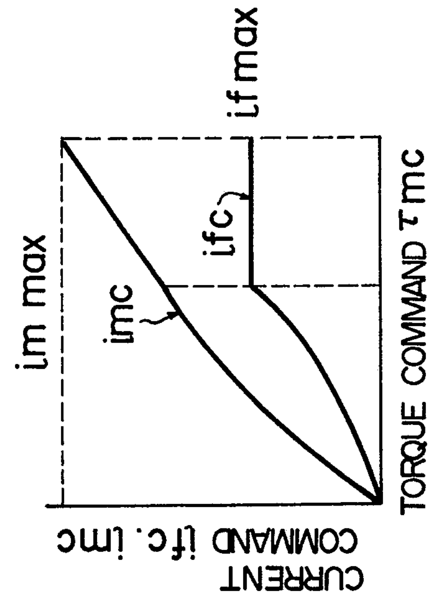


FIG. 3

FIG. 4

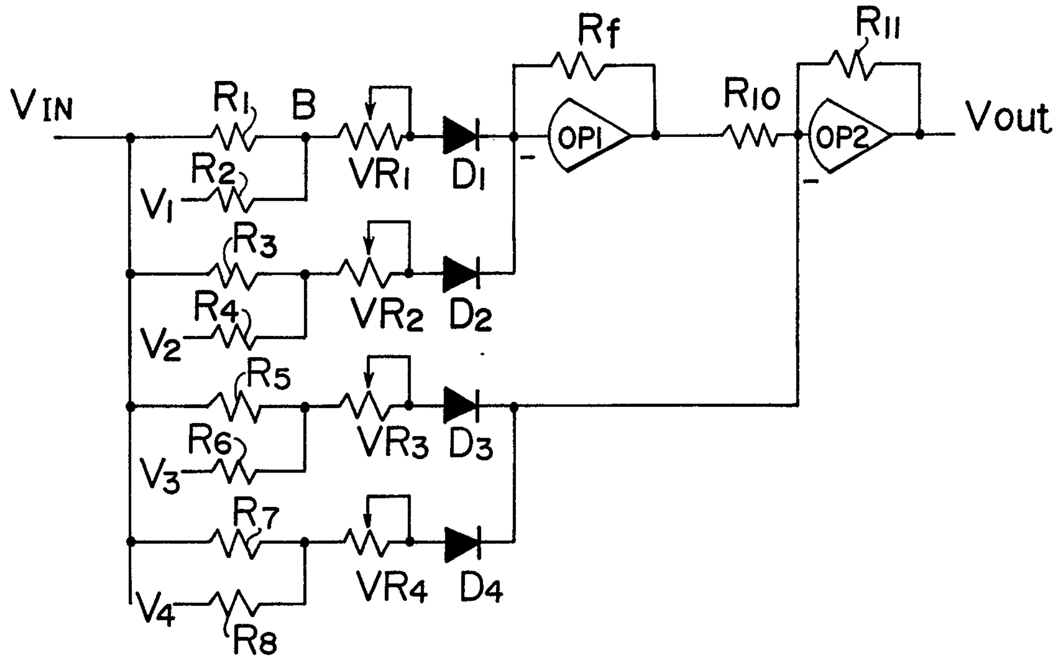

VIN
R1
B
R2
V1
VR1
D1
Rf
OP1
R10
R11
OP2
Vout
R3
VR2
D2
R4
V2
R5
VR3
D3
R6
V3
R7
VR4
D4
V4
R8

FIG. 5

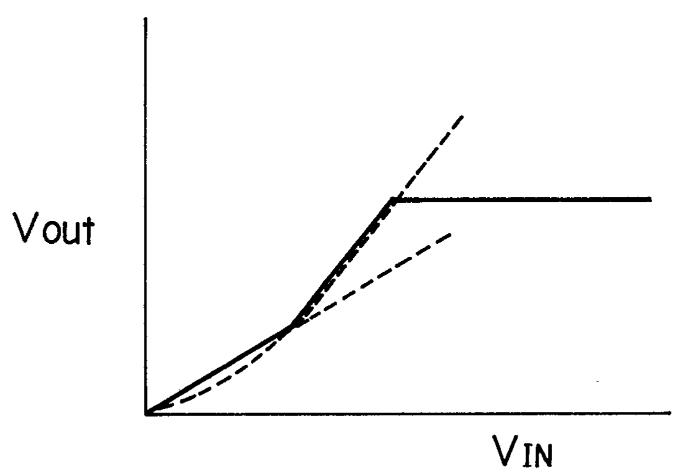

Vout
VIN

FIG. 6

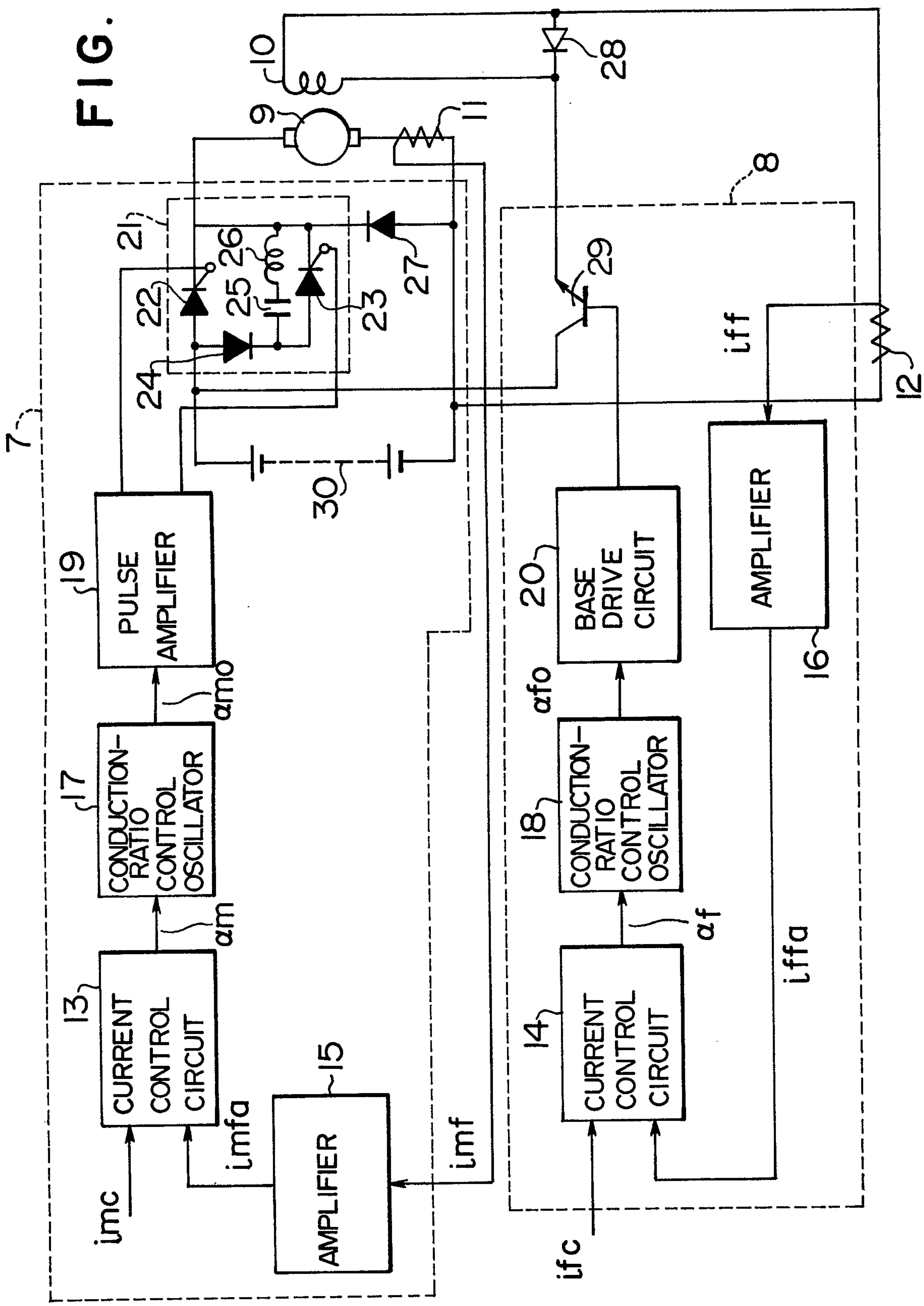

PULSE AMPLIFIER
CONDUCTION-RATIO CONTROL OSCILLATOR
CURRENT CONTROL CIRCUIT
AMPLIFIER
BASE DRIVE CIRCUIT
AMPLIFIER
CONDUCTION-RATIO CONTROL OSCILLATOR
CURRENT CONTROL CIRCUIT
imc
imfa
imf
am
amo
ifc
af
afo
iff
iffa

FIG. 7

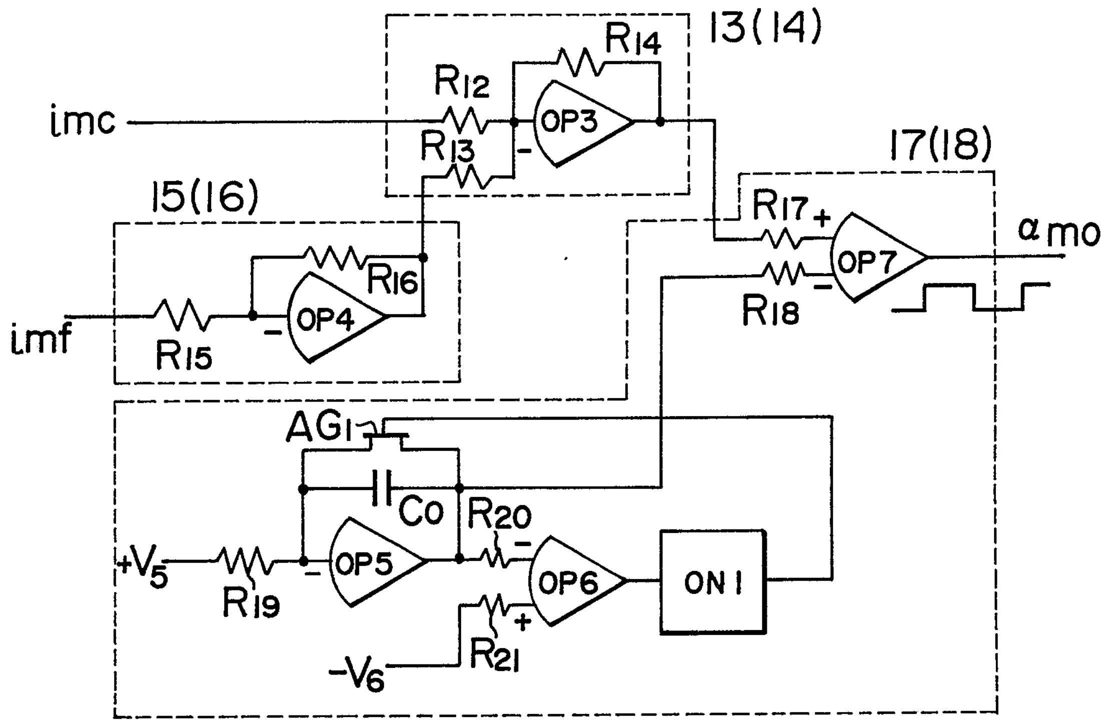
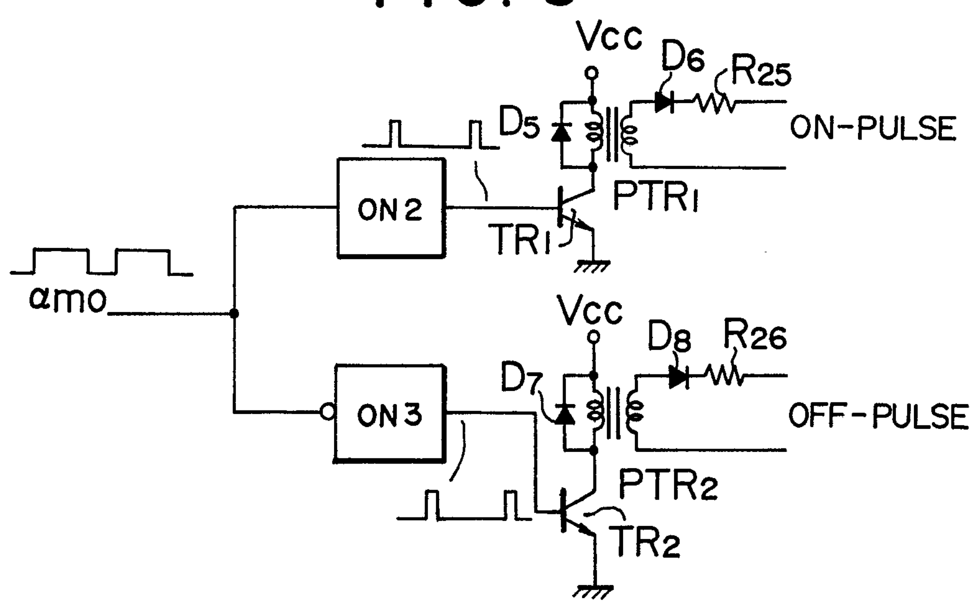

13(14)
R14
R12
imc
OP3
R13
17(18)
15(16)
R17
αmo
R16
OP7
R18
OP4
imf
R15
AG1
Co
R20
+V5
OP5
OP6
ON1
R19
R21
-V6

FIG. 8


Vcc
D6
R25
D5
ON-PULSE
ON2
PTR1
TR1
αmo
Vcc
D8
R26
D7
ON3
OFF-PULSE
PTR2
TR2

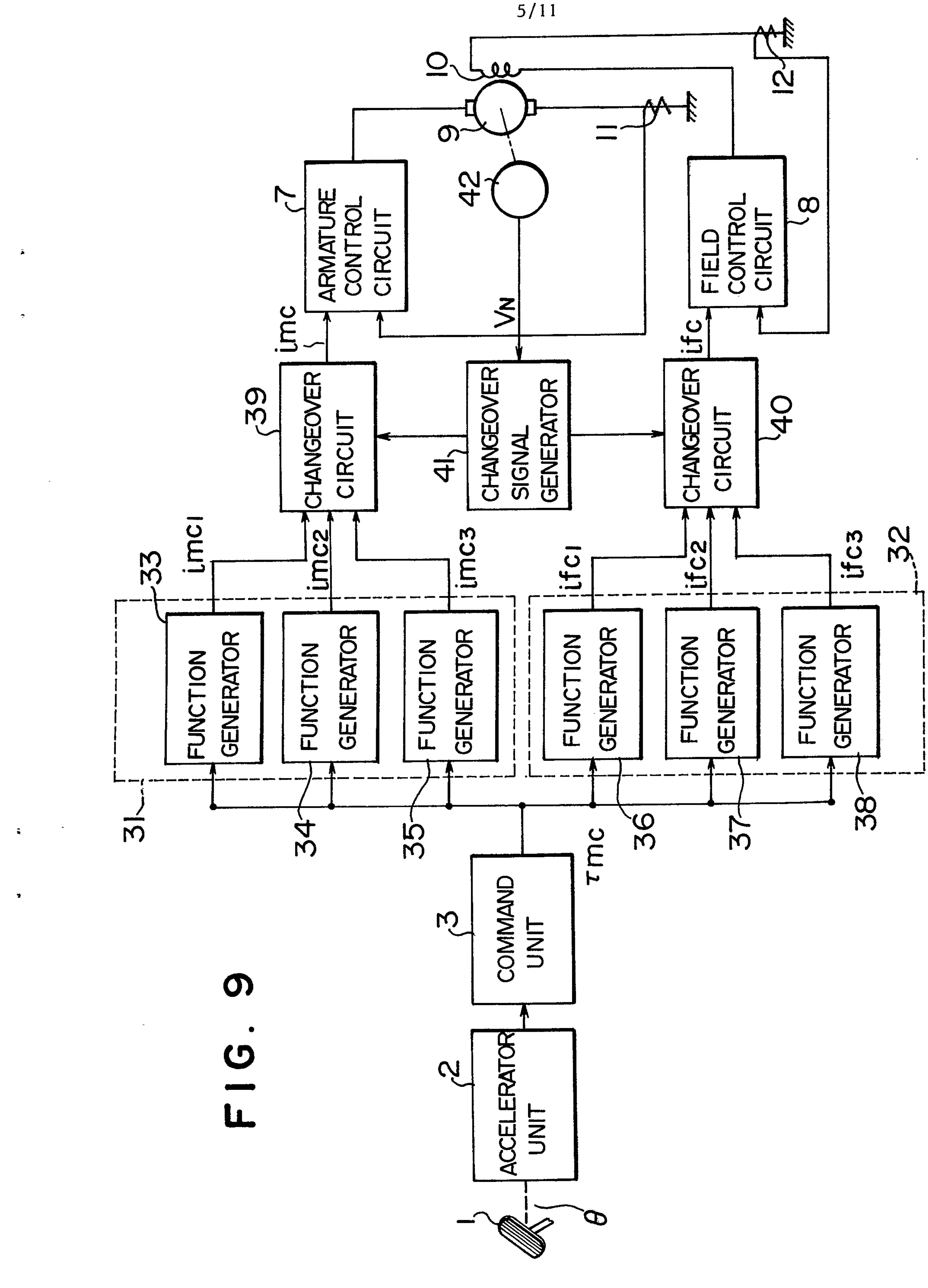

ACCELERATOR UNIT
COMMAND UNIT
FUNCTION GENERATOR
FUNCTION GENERATOR
FUNCTION GENERATOR
FUNCTION GENERATOR
FUNCTION GENERATOR
FUNCTION GENERATOR
CHANGEOVER CIRCUIT
CHANGEOVER SIGNAL GENERATOR
CHANGEOVER CIRCUIT
ARMATURE CONTROL CIRCUIT
FIELD CONTROL CIRCUIT
1
2
3
7
8
9
10
11
12
31
32
33
34
35
36
37
38
39
40
41
42
θ
τmc
imc1
imc2
imc3
ifc1
ifc2
ifc3
imc
ifc
VN

FIG. 9

FIG. 10

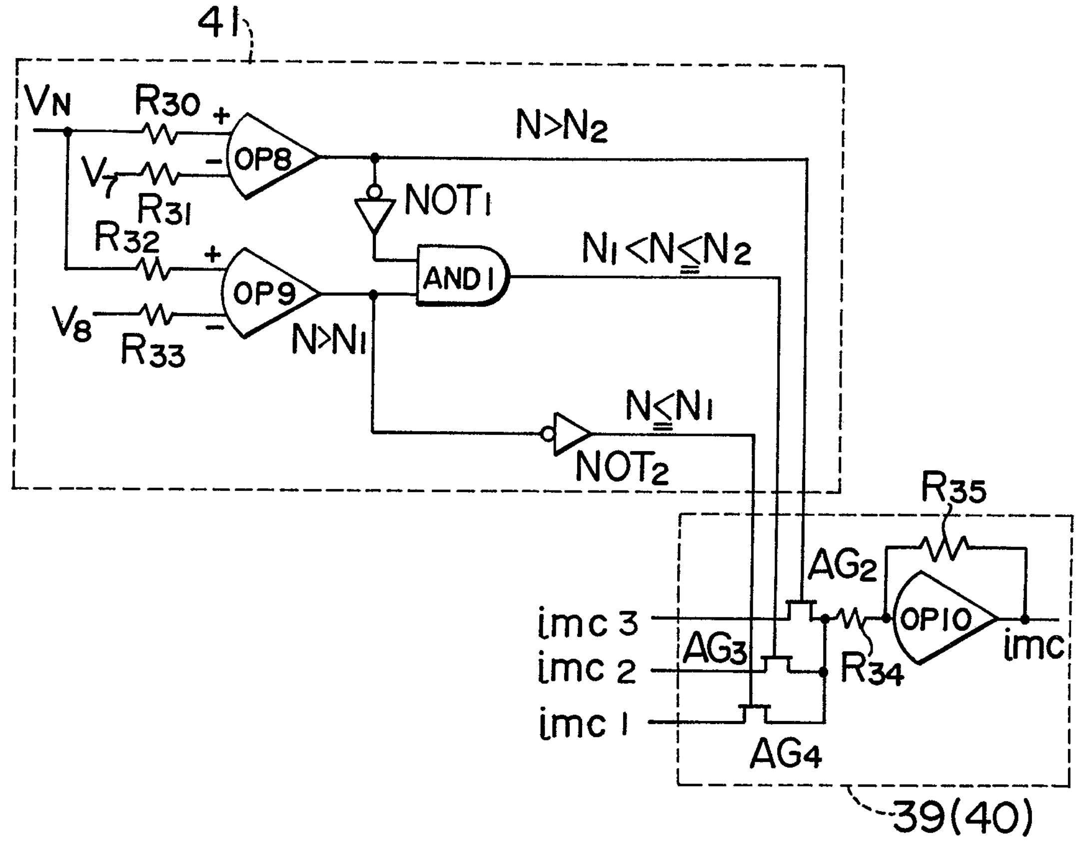

41
VN
R30
R31
R32
R33
V7
V8
OP8
OP9
NOT1
NOT2
AND1
N>N2
N1<N≦N2
N>N1
N≦N1
R35
AG2
AG3
AG4
R34
OP10
imc 3
imc 2
imc 1
imc
39(40)

FIG. 11

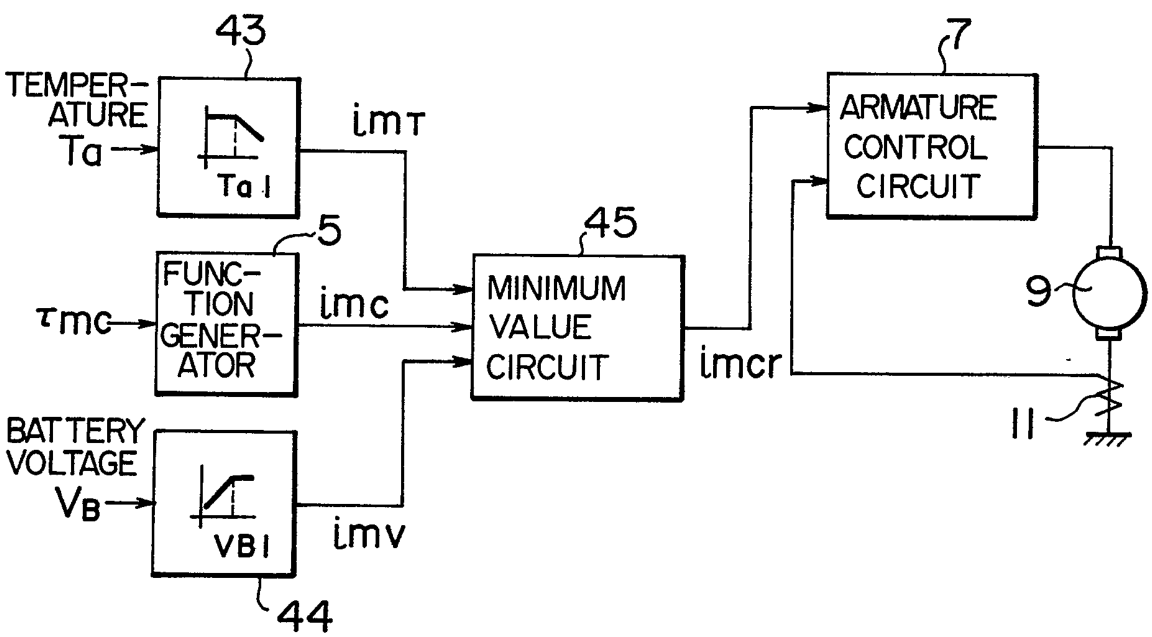

43
TEMPERATURE
Ta
Ta1
imT
5
FUNCTION GENERATOR
τmc
imc
BATTERY VOLTAGE
VB
VB1
imv
44
45
MINIMUM VALUE CIRCUIT
imcr
7
ARMATURE CONTROL CIRCUIT
9
11

FIG. 12

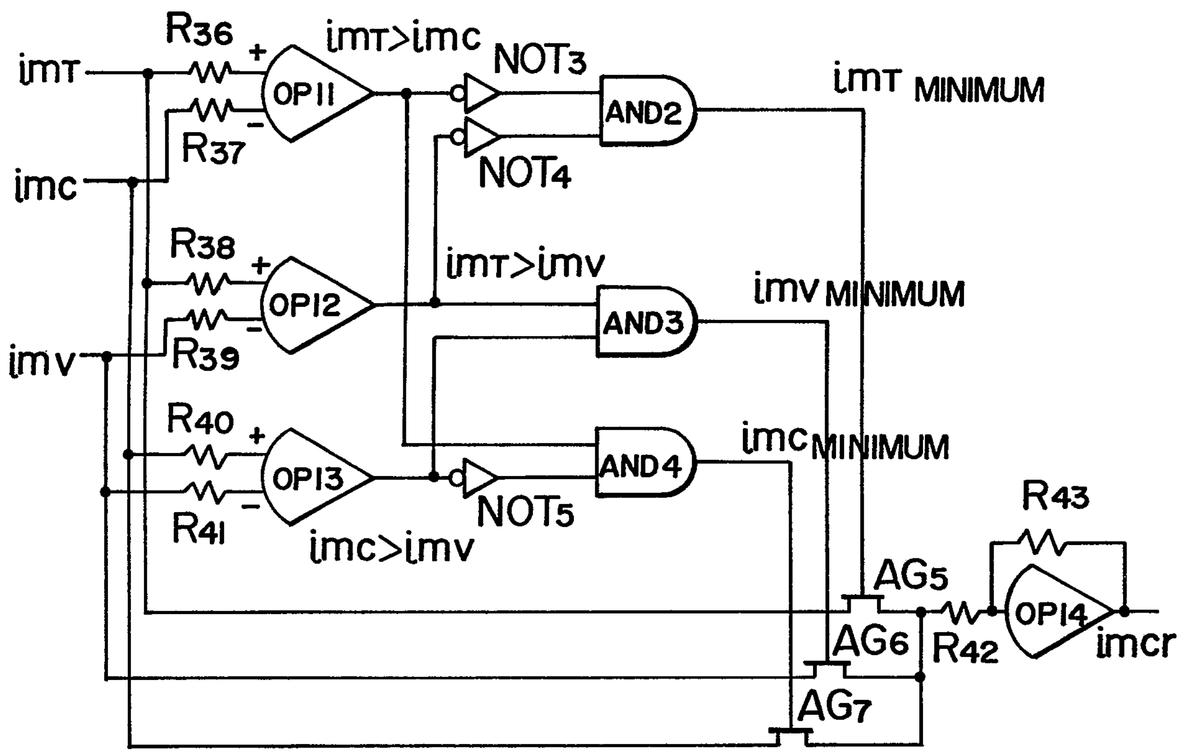

imT
imc
imv
R36
R37
R38
R39
R40
R41
+
−
OP11
OP12
OP13
imT>imc
imT>imv
imc>imv
NOT3
NOT4
NOT5
AND2
AND3
AND4
imT MINIMUM
imv MINIMUM
imc MINIMUM
AG5
AG6
AG7
R42
R43
OP14
imcr

FIG. 13

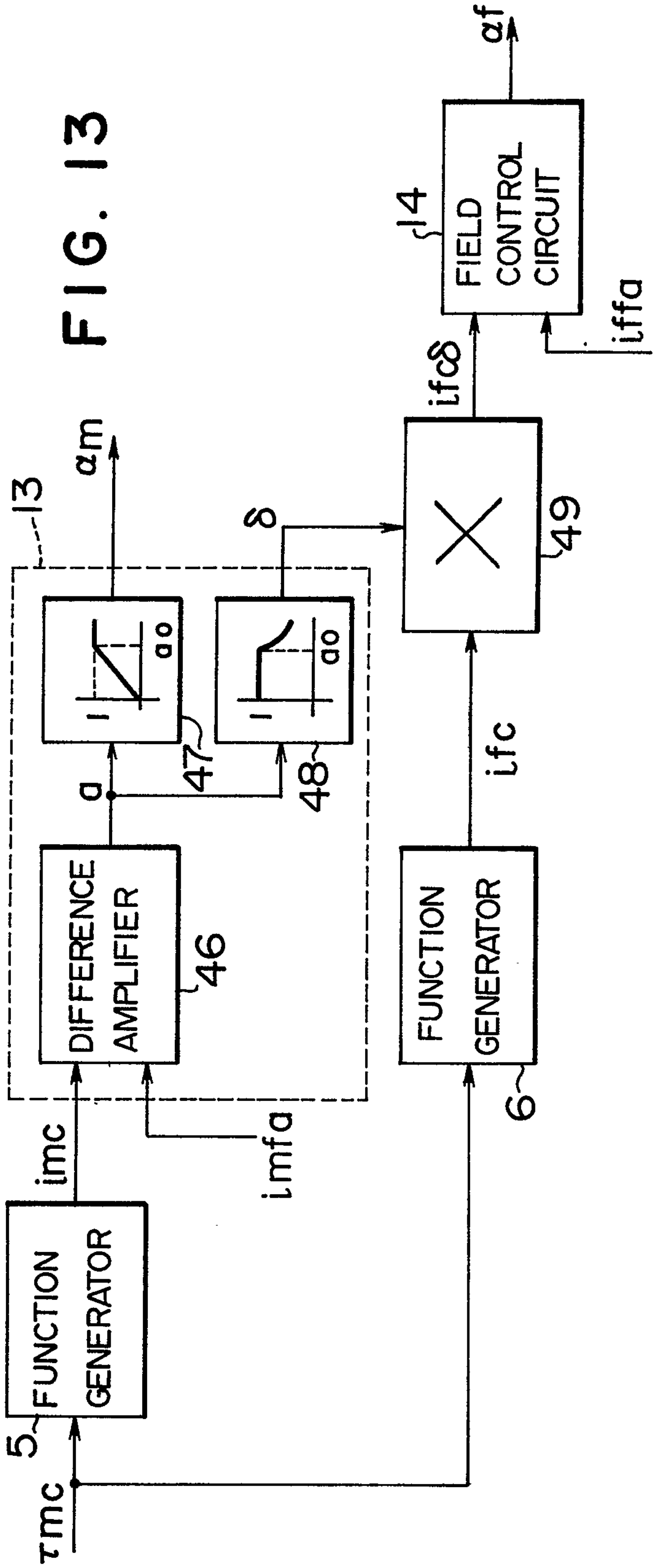
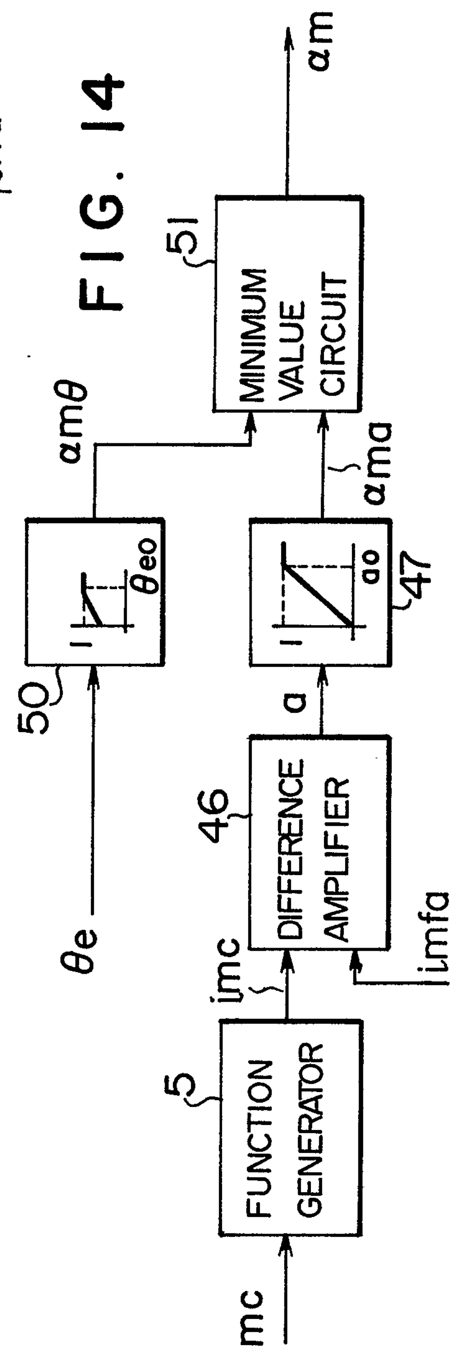

τmc
5
FUNCTION GENERATOR
imc
imfa
DIFFERENCE AMPLIFIER
46
a
47
48
ao
13
αm
δ
49
6
FUNCTION GENERATOR
ifc
ifcδ
14
FIELD CONTROL CIRCUIT
iffa
αf

FIG. 14


θe
50
θeo
αmθ
τmc
5
FUNCTION GENERATOR
imc
46
DIFFERENCE AMPLIFIER
imfa
a
47
ao
αma
51
MINIMUM VALUE CIRCUIT
αm

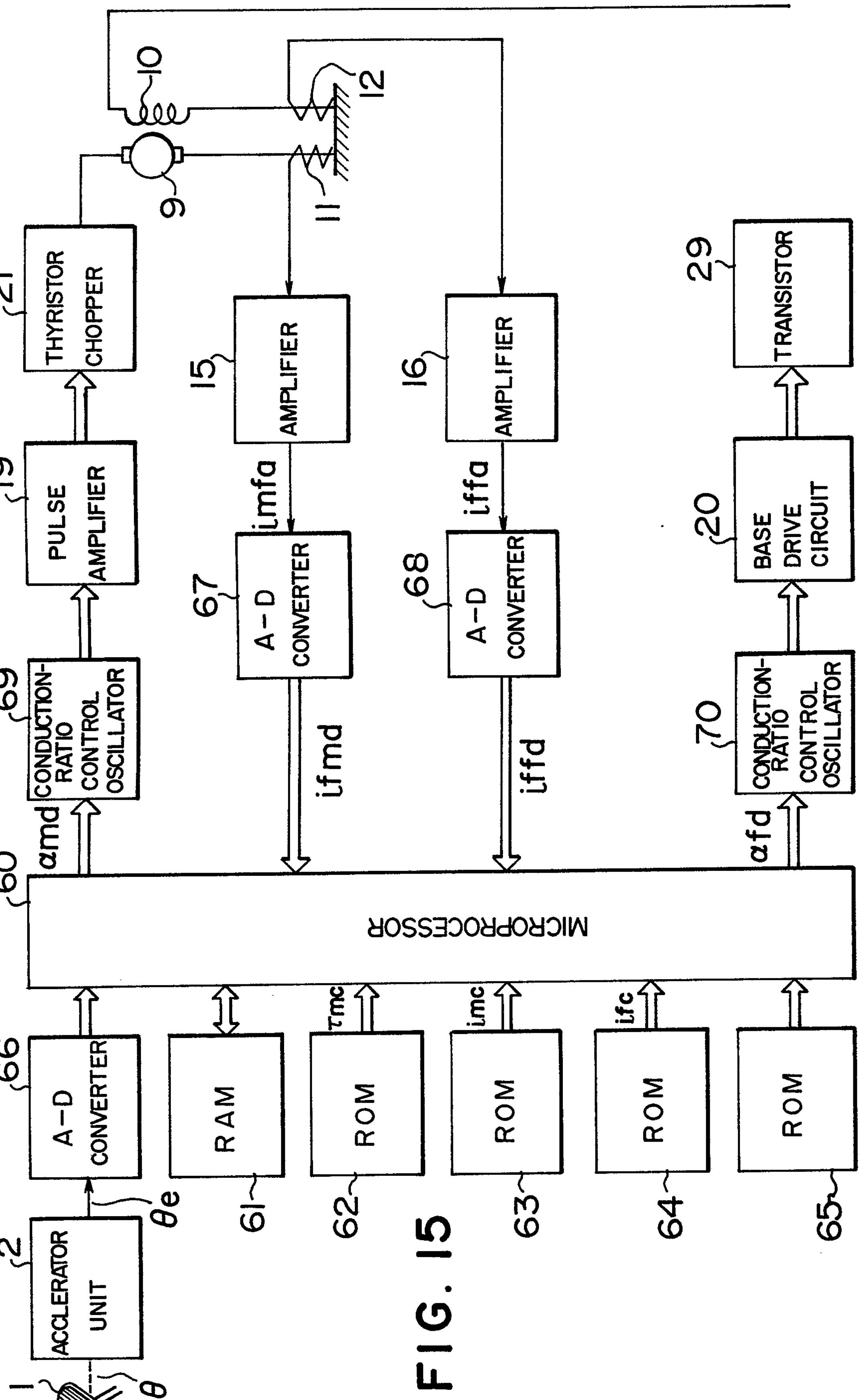

THYRISTOR CHOPPER
PULSE AMPLIFIER
CONDUCTION-RATIO CONTROL OSCILLATOR
AMPLIFIER
A-D CONVERTER
AMPLIFIER
A-D CONVERTER
TRANSISTOR
BASE DRIVE CIRCUIT
CONDUCTION-RATIO CONTROL OSCILLATOR
MICROPROCESSOR
ACCLERATOR UNIT
A-D CONVERTER
RAM
ROM
ROM
ROM
ROM
imfa
iffa
ifmd
iffd
αmd
αfd
θe
θ
τmc
imc
ifc
1
2
9
10
11
12
15
16
19
20
21
29
60
61
62
63
64
65
66
67
68
69
70

FIG. 15

FIG. 16

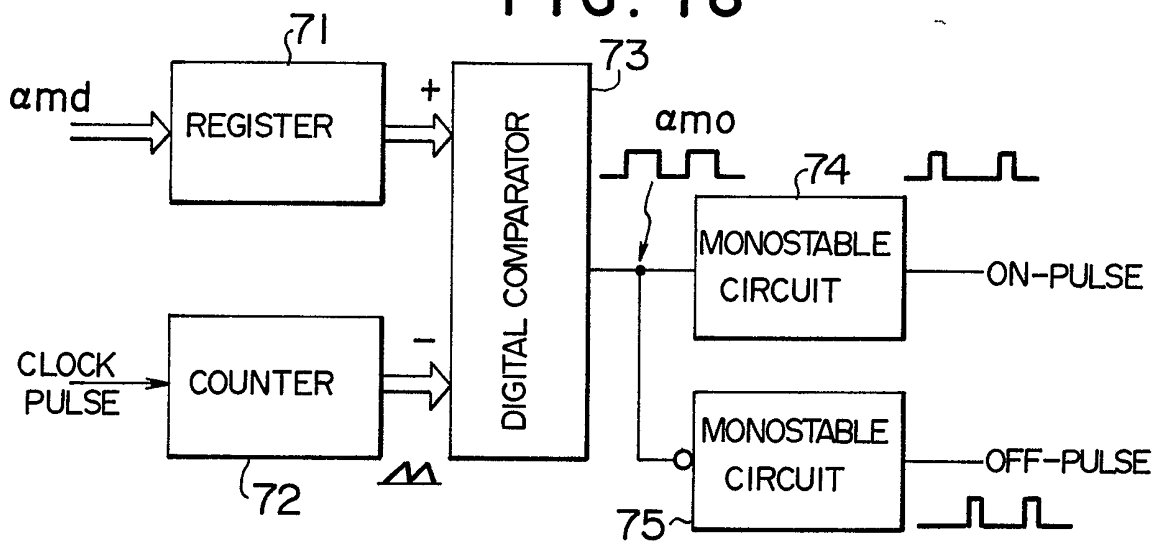


FIG. 17

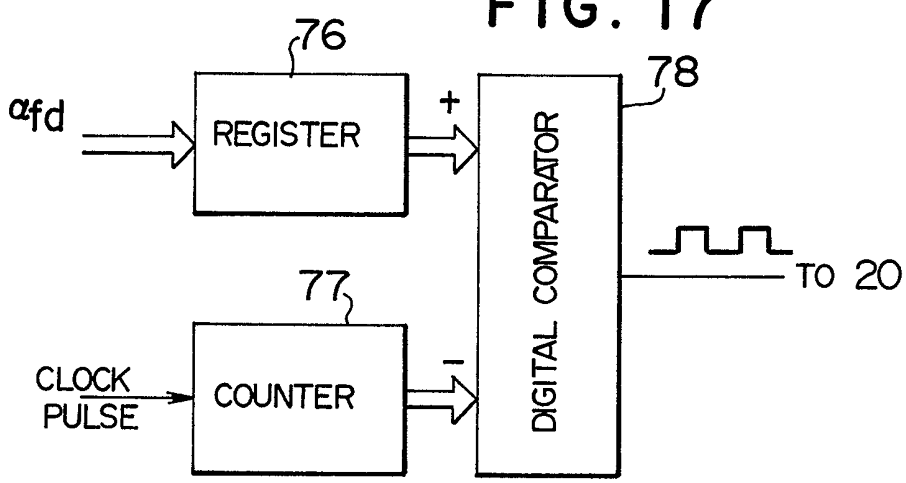


FIG. 18

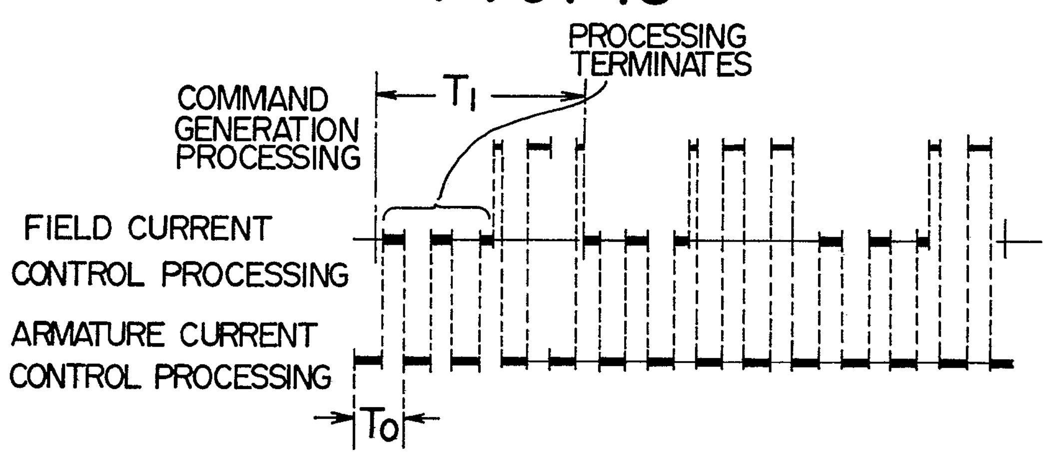


FIG. 19

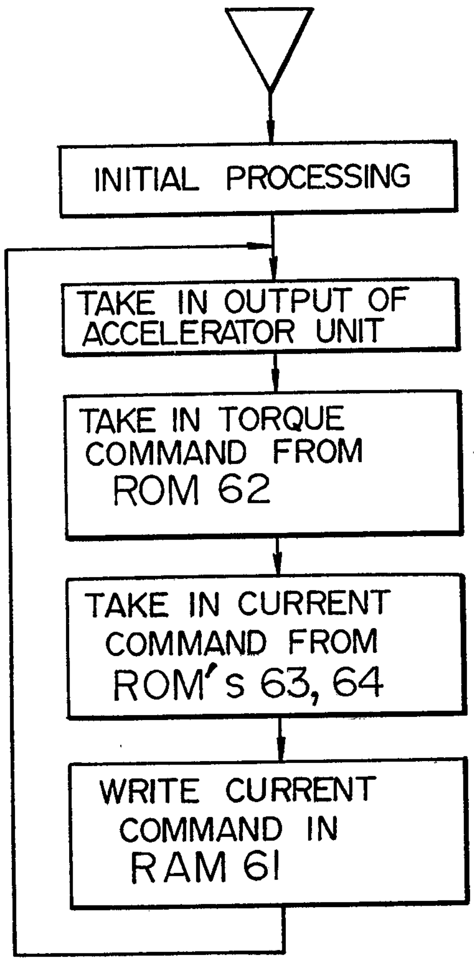


FIG. 20

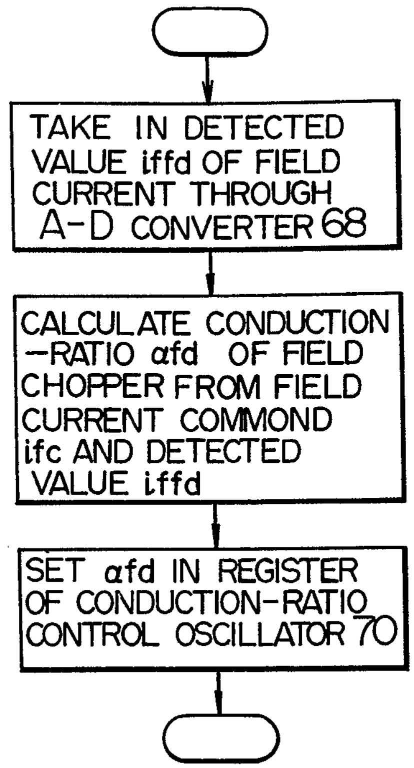
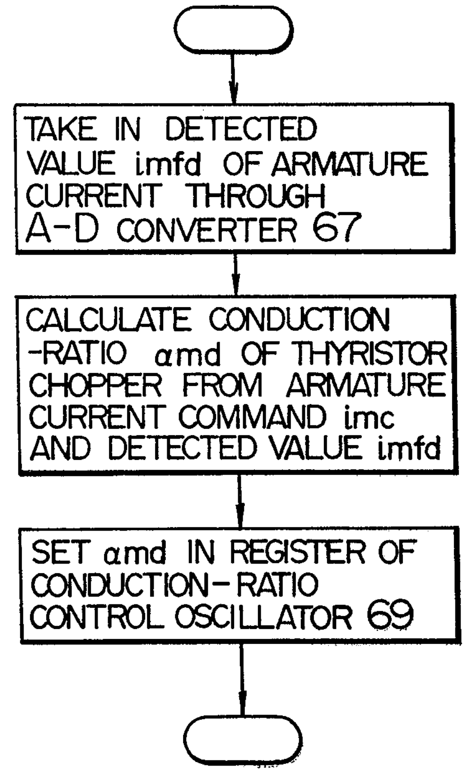


FIG. 21



SPECIFICATION

Electromobile control device

The present invention relates to a control device for an electromobile equipped with a shunt motor, and more particularly to a control device for driving a shunt motor by armature and field currents which can generate at the highest efficiency a motor output torque specified in accordance with how much an accelerator pedal is trodden.

An electromobile uses a storage battery as the power source thereof and is relatively short in travelling distance. Therefore, it is demanded to make the loss in the driving system of the electromobile as small as possible. Further, since the electromobile passes a road together with an automobile with gasoline engine, it is required that the electromobile is easy to operate as in the case of the automobile with gasoline engine. To this end, an electromobile control device has been known in which a shunt motor is employed as the driving motor of an electromobile. For example, a U.S. Patent 4,037,144 discloses a control device of such a shunt motor. In this control device, in order to minimize the total loss in the driving system of electromobile, the armature current of the shunt motor is detected and the field current thereof is controlled so as to have an optimum value on the basis of the detected value of armature current. However, this device has a drawback that the selected value of field current is affected by a dynamic characteristic of the armature current.

An object of the present invention is to provide an electromobile control device capable of driving a shunt motor at the highest efficiency to generate a selected output torque.

Another object of the present invention is to provide an electromobile control device equipped with a pattern generator for storing, as predetermined patterns, armature and field currents which can drive an electric motor at the highest efficiency thereof to generate an output torque of electric motor specified in accordance with an angle of an accelerator pedal trodden.

A further object of the present invention is to provide an electromobile control device making use of a microcomputer for driving a shunt motor at its highest efficiency under a selected output torque.

In order to attain the above objects, according to an aspect of the present invention, there is provided a control device for an electromobile provided with a shunt motor comprising: a command unit for generating an output torque command of the shunt motor in accordance with angle of an accelerator pedal trodden; a pattern generating means for storing, as predetermined patterns, armature and field currents capable of generating an output torque of the shunt motor indicated by the output torque command in such a manner as producing a minimum loss in the driving system of the electromobile, and for generating an armature current command and a field current command in accordance with the predetermined patterns and the output torque command; armature control means for passing an armature current corresponding to the armature current command through the armature winding of the shunt motor; and field control means for passing a field current corresponding to the field current command through the field winding of the shunt motor.

Further, according to another aspect of the present invention, there is provided a control device for an electromobile provided with a shunt motor comprising: a command means for generating an output torque command of the shunt motor in accordance with an angle of an accelerator pedal trodden; memory means for storing predetermined patterns respectively indicating armature and field currents capable of generating an output torque of the shunt motor indicated by the output torque command in such a manner as producing a minimum loss in the driving system in the electromobile; a microprocesser for calculating an armature current command and a field current command corresponding respectively to the armature and field currents producing the minimum loss, in a predetermined processing order, on the basis of the output torque command and the predetermined patterns, and for delivering the armature current command and the field current command; armature control means for passing an armature current corresponding to the armature current command through the armature winding of the shunt motor; and field control means for passing a field current corresponding to the field current command through the field winding of the shunt motor.

The foregoing and other objects, features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawing, in which:

Fig. 1 is a block diagram showing an embodiment of an electromobile control device according to the present invention;

Fig. 2 is a graph showing a relation between an angle θ of accelerator pedal trodden and a torque command τ_{mc};

Fig. 3 is a graph showing relations between a torque command τ_{mc} and current commands i_{fc} and i_{mc} based upon predetermined patterns;

Fig. 4 is a circuit diagram for showing an example of a function generator used in the present invention;

Fig. 5 is a graph showing an input-output characteristic of the function generator shown in Fig. 4;

Fig. 6 is a block diagram showing both the armature control circuit and the field control circuit which are included in the embodiment shown in Fig. 1.;

Fig. 7 is a circuit diagram for showing an example of the armature control circuit shown in Fig. 6;

Fig. 8 is a circuit diagram for showing an example of the pulse amplifier shown in Fig. 6;

Fig. 9 is a block diagram showing another embodiment of an electromobile control device according to the present invention;

Fig. 10 is a circuit diagram for showing an example of that circuit part of the embodiment shown in Fig. 9 which includes the changeover circuit and the changeover signal generator;

Fig. 11 is a block diagram showing a part of a further embodiment of an electromobile control device according to the present invention, which embodiment includes protection means in addition to the circuit arrangement shown in Fig. 1;

Fig. 12 is a circuit diagram for showing an example of the minimum value circuit shown in Fig. 11;

Fig. 13 is a block diagram showing a part of a different embodiment of an electromobile control device according to the present invention, which embodiment includes means for conducting a field-weakening control, in addition to the circuit arrangement shown in Fig. 1;

Fig. 14 is a block diagram showing a part of an additional embodiment of an electromobile control device according to the present invention, which embodiment includes means for limiting the conduction ratio of a chopper to a maximum value, in addition to the circuit arrangement shown in Fig. 1;

Fig. 15 is a block diagram showing still another embodiment of an electromobile control device according to the present invention, which embodiment employs a microprocessor;

Fig. 16 is a block diagram showing one conduction-ratio control oscillator shown in Fig. 15;

Fig. 17 is a block diagram showing the other conduction-ratio control oscillator shown in Fig. 15;

Fig. 18 is a time chart for explaining the processing made by the microprocessor shown in Fig. 1; and

Figs. 19 to 21 are flow charts for explaining the command generation processing, field-current control processing and armature-current control processing, respectively. In the drawings, like reference numerals refer to like parts.

Now, explanation will be made on an embodiment of an electromobile control device according to the present invention. In Fig. 1 showing the above embodiment, reference numeral 1 designates an accelerator pedal, 2 an accelerator unit for generating an electric output in accordance with how much the accelerator pedal is trodden, namely, an angle θ of the accelerator pedal trodden, 3 a command unit for generating an output torque command τ_{mc} of a shunt motor 9 based upon the output θ_e of the accelerator unit 2, 4 a pattern generating means made up of two function generators 5 and 6 for generating an armature current command i_{mc} and a field current command i_{fc}, 7 an armature control circuit for controlling the current flowing through the armature winding of the shunt motor 9, 8 a field control circuit for controlling the current flowing through the field winding 10, and 11 and 12 detectors for detecting armature and field currents, respectively.

Now, the operation of the embodiment shown in Fig. 1 will be explained below.

When the accelerator pedal is trodden, the accelerator unit 2 delivers the electric output θ_e corresponding to the angle θ of the accelerator pedal trodden, and the command unit 3 generates the torque command τ_{mc}. For example, there is such a relation as shown in Fig. 2 between the angle θ of accelerator pedal and the torque command τ_{mc}. The output τ_{mc} of the command unit 3 is applied to the pattern generator 4 made up of the function generators 5 and 6, which generates the armature current command i_{mc} and the field current command i_{fc}, respectively. The functions generated in the function generators are determined in the following manner. When the armature current and field currents of the shunt motor are expressed by i_m and i_f, respectively, the torque τ_m of the motor is given by the following equation:

$$\tau_m = k i_m i_f \qquad \text{......} \quad (1)$$

where k denotes a constant.

While, the total loss W in the driving system of the embodiment shown in Fig. 1 is given by the following equation:

$$W = f(i_m, i_f, N) \qquad \text{......} \quad (2)$$

where N denotes the number of rotations of the motor.

Now, let us consider a case where the loss depending upon the number N of rotations is separable from the remaining loss, then, equation (2) can be rewritten in the following manner:

$$W = g_1(i_m, i_f) + g_2(N) \qquad \text{......} \quad (3)$$

Assuming that the output torque is at constant, a relation between i_m and i_f at which the total loss W has a minimum value, is obtained experimentally on the basis of the equation (3) and is expressed in the following manner:

$$i_m = g_3(i_f) \qquad \text{......} \quad (4)$$

The following equation is obtained by substituting $g_3(i_f)$ for i_m of equation (1):

$$\tau_m = k \cdot i_f \cdot g_3(i_f) \qquad \text{......} \quad (5)$$

When the torque τ_m is given, the field current i_f is determined by equation (5), and then the armature current i_m is determined by equation (4).

In more detail, for example, the previously-mentioned U.S. Patent 4,037,144 discloses the following empirical equation which expresses the total loss W excepting the loss $g_2(N)$ depending upon the number of rotations.

$$W = k_1 i_m^2 + k_2 i_f^2 + W_c \qquad \text{......} \quad (6)$$

where W_c denotes a constant mechanical loss, and k_1 and k_2 a constant respectively. Further, in the above patent, the armature and field currents i_m and i_f are given by the following equations:

$$i_m = \sqrt[4]{\frac{k_2 \tau^2}{k_1 k^2}} \qquad \text{......} \quad (7)$$

$$i_f = \sqrt[4]{\frac{k_1 \tau^2}{k_2 k^2}} \qquad \text{......} \quad (8)$$

Thus, armature and field currents which reduce the total loss W to a minimum value, are readily obtained for a constant torque.

The function generator 6 incorporated in the embodiment shown in Fig. 1 delivers the output based upon the relation given by equation (5) or (8) between the field current and the torque, and the function generator 5 delivers the output based upon the relation given by the combination of equations (4) and (5) or equation (7) between the armature current and the torque.

A main feature of the present invention resides in that each of armature and field currents capable of driving the shunt motor with a minimum loss for an output torque command is stored in each of the function generators (5) and (6) in the form of a predetermined pattern.

Fig. 3 shows an example of each of functions stored in the function generators (5) and (6). As is seen in Fig. 3, a maximum current at which field saturation takes place, is indicated by i_{fmax}, and only the armature current i_{mc} is increased within a range of torque requiring the maximum field current.

Although the function generators satisfying the above relations between the armature and field currents and the output torque can be readily formed by those skilled in the art, an example thereof is shown in Fig. 4. In Fig. 4, reference symbols V_1 to V_4 designate reference voltages, OP1 and OP2 operational amplifiers, V_{IN} an input signal corresponding to τ_{mc}, and V_{OUT} an output signal corresponding to i_{mc} or i_{fc}. The circuit shown in Fig. 4 can produce, for example, the input-output characteristic shown in Fig. 5 when appropriate circuit constants are employed.

Next, the armature control circuit (7) and the field control circuit (8) which are shown in Fig. 1, will be explained below in detail by reference to Fig. 6. In Fig. 6, reference numeral 13 designates a current control circuit for producing an armature current corresponding to an armature current command i_{mc}, from both the command i_{mc} and an amplified signal i_{mfa}, through a feedback control, 15 an amplifier for amplifying a detected current signal i_{mf} to deliver the amplified signal i_{mfa}, 17 a conduction-ratio control oscillator for defining the conduction ratio of a thyristor chopper 21 in accordance with the output of the current control circuit 13, 19 a pulse amplifier for amplifying the output signal α_{mo} of the oscillator 17, 30 a storage battery serving as a power source, 22 and 23 thyristors, 24 a diode, 25 commutation capacitor, 26 a commutation reactor, and 27 a flywheel diode. The above circuits and elements make up the armature control circuit 7.

Similarly, the field control circuit 8 includes a current control circuit 14, a conduction-ratio control oscillator 18, a base drive circuit 20 for a transistor 29, an amplifier 16, a fly-wheel diode 28, and the transistor 29, and supplies a field winding 10 with a field current corresponding to a field current command i_{fc}.

A circuit arrangement of the part which includes the amplifier 15 (or 16), the current control circuit 13 (or 14) and the conduction-ratio control oscillator 17 (or 18), is shown in Fig. 7, and an example of the pulse amplifier 19 is shown in Fig. 8. In Figs. 7 and 8, reference symbols OP3 to OP7 designate operational amplifiers, and ON1 to ON3 monostable circuits.

The armature current command i_{mc} delivered from the function generator detector 11 are processed in the circuits shown in Figs. 7 and 8 to deliver from the amplifier 19 an on-pulse and an off-pulse each for controlling the thyristors 22 and 23. The current control circuit 14, the conduction-ratio control oscillator 18 and the amplifier 16 which are included in the field control circuit 8, may have the same circuit construction as those shown in Fig. 7. Accordingly, the field current command i_{fc} delivered from the function generator 6 and the output signal i_{ff} of the field current detector 12 are processed in a similar manner, and thus an appropriate field current is supplied to the field winding.

In the above-mentioned embodiment, an armature current and a field current which can drive a shunt motor with a minimum loss, are independently selected by the pattern generator 4 on the basis of an output torque command corresponding to an angle of accelerator pedal. Accordingly, the shunt motor can be driven at its highest efficiency.

Fig. 9 shows another embodiment of an electromobile control device according to the present invention. The embodiment shown in Fig. 1 is used in a case where equation (2) can be converted into equation (3). In fact, there is a case where the loss depending upon the number of rotations cannot be separated. In such a case, information on the number of rotations of motor has to be considered in the pattern generating means. Fig. 9 shows one embodiment applicable to this case. Referring to Fig. 9, a pattern generating means 31 for generating the armature current command includes function generators 33, 34 and 35, and another pattern generating means 32 for generating the field current command includes function generators 36, 37 and 38. Further, the embodiment shown in Fig. 9 includes a changeover circuit 39 for selecting one of the outputs i_{mc1}, i_{mc2} and i_{mc3} of the function generators 33, 34 and 35, a changeover circuit 40 for selecting one of the outputs i_{fc1}, i_{fc2} and i_{fc3} of the function generators 36, 37 and 38, a changeover signal generator 41 for generating a changeover signal, and a tachometer generator 42. The function generators 33 and 36 store functions which can drive a shunt motor 9 with a minimum loss when the motor 9 is low in the number of rotations, the function generators 34 and 37 are used when the motor 9 is intermediate in the number of rotations, and the function generators 35 and 38 store functions capable of driving the motor 9 with a minimum loss when the number of rotations is high. In other words, the pattern generating means 31 and 32 includes three sets of functions corresponding to three ranges of the number of rotations. A function set in each of the function generators 33 to 38 is determined on the basis of a predetermined pattern, and each function generator may have the same circuit construction as shown in Fig. 4.

Fig. 10 shows examples of the changeover signal generator 41 and changeover circuit 39 (or 40). The changeover signal generator 41 shown in Fig. 10 includes resistors R_{30}, R_{31}, R_{32} and R_{33}, operational amplifiers OP8 and OP9, NOT circuits NOT 1 and NOT 2, and an AND circuit AND 1. The output voltage V_N of the tachometer generator 42 is applied through the resistor R_{30} to the positive input terminal of the operational amplifier OP 8 to be compared with a constant voltage V_7 which corresponds to the number of rotations of motor equal to N_2. Accordingly, the output of the operational amplifier OP8 is put in the level of "1" when the number N of rotations is greater than N_2. The output voltage V_N is also applied to the operational amplifier OP 9 to be compared with a constant voltage V_8 which corresponds to the number of rotations equal to N_1. The output of the operational amplifier OP 9 assumes the level of "1" when the number N of rotations is greater than N_1. The AND circuit AND 1 is applied through the NOT circuit NOT 1 with the output of the operational amplifier OP 8, and is directly applied with the output of the operational amplifier OP 9. Accordingly, the output of the AND circuit AND 1 assumes the level of "1" when the number N of rotations satisfies a relation $N_1 < N \leq N_2$. Further, the output of the operational amplifier OP 9 is applied to the NOT circuit NOT 2, and therefore the NOT circuit NOT 2 delivers the output signal having the level of "1" when the number N of rotations satisfies a relation $N \leq N_1$.

The changeover circuit 39 (or 40) shown in Fig. 10 includes analog gates AG2, AG3 and AG4, resistors R_{34} and R_{35} and an operational amplifier OP10. When the number N of rotations is greater than N_2, the gate AG2 becomes conductive and the input i_{mc3} is applied to the operational amplifier OP 10 through the resistor R_{34} to form the current command i_{mc}. Similarly, the gate AG3 or AG4 becomes conductive according as the relation $N_1 < N \leq N_2$ or $N \leq N_1$ is satisfied. Thus, the input i_{mc2} or i_{mc1} is applied to the operational amplifier OP 10 to form the current command i_{mc}.

The torque command τ_{mc} has a constant value during the angle θ of accelerator pedal is kept constant In such a state, when the tachometer generator 42 detects that the shunt motor 9 is low in the number of rotations, the output of the changeover signal generator 41 operates the changeover circuits 39 and 40 so as to form the armature current command i_{mc} and the field current command i_{fc} by the output i_{mc1} of the function generator 33 and the output i_{fc1} of the function generator 36, respectively. As a result, an armature current and a field current are employed which can drive the shunt motor 9 with a minimum loss in a range of number of rotations which includes the number of rotations now used.

As mentioned above, the embodiment shown in Fig. 9 takes the number of rotations of motor into consideration, and can drive the motor 9 by a combination of armature and field currents which produces a minimum loss, even in such a case that equation (2) cannot be converted into equation (3).

Fig. 11 shows, in block, a part of a further embodiment of an electromobile control device according to the present invention. Since this embodiment is different only in a part for determining the armature current command from the embodiment shown in Fig. 9, only the above part is shown in Fig. 11. In more detail, in the embodiment shown in Fig. 11, a function of detecting the temperature of the shunt motor or the control device in order to protect them and a function of protecting a storage battery when the voltage thereof is decreased, are added to the embodiment shown in Fig. 1. When the temperature of the driving system of electromobile becomes high, or when the voltage of the storage battery is decreased, the armature current is usually made small to protect the driving system and the battery. The embodiment shown in Fig. 11 is applicable to such a case.

Referring to Fig. 11, the function set in the function generator 43 has such a form as shown in a block indicated by reference numeral 43. That is, the output imT of the function generator 43 is decreased as the temperature T_a of the motor 9 becomes higher in a temperature range exceeding a predetermined temperature T_{a1}. Further, the function set in the function generator 44 has such a form as shown in a block 44. That is, the function generator 44 delivers a constant output i_{mV} when the battery voltage V_B is increased to a voltage range exceeding a predetermined mined voltage V_{B1}. The outputs i_{mT}, i_{mc} and i_{mV} are applied to a minimum value circuit 45. Fig. 12 shows an example of the circuit construction of the minimum value circuit 45. The smallest one of the outputs i_{mT}, i_{mc} and i_{mV} is selected by the circuit 45, and is applied to the armature control circuit 7 to pass a desired current through the armature winding of the shunt motor 9. In other words, the outputs i_{mT} and i_{mV} are used as limit signals for limiting the armature current.

According to the above embodiment, the armature current is reduced, when the temperature of the shunt motor becomes high, and when the battery voltage is decreased. Thus, the safety of electromobile can be enhanced.

Fig. 13 shows a part of a different embodiment of an electrode control device according to the present invention. This embodiment includes means for conducting the field-wakening control in addition to the circuit construction shown in Fig. 1. In more detail, the current control circuit 13 (such as shown in Fig. 6) of this embodiment is made up of a difference amplifier 46 and function generators 47 and 48. As is shown in blocks 47 and 48, the function generator 47 delivers a constant output when the output *a* of the amplifier 46 is increased to a range exceeding a predetermined value a_o, and the output of the function generator 48 is decreased as the output *a* of the amplifier 46 becomes greater in a range exceeding the value a_o. A multiplier 49 multiplies the output i_{fc} of the function generator 6 by the output δ of the function generator 48 to apply the product $i_{fc} \cdot \delta$ to the field control circuit 14.

As the number of rotations of motor becomes higher in a state that both the output i_{mc} of the function generator 5 and the conduction-ratio α_m of chopper are kept constant, the counter electromotive force of the motor is increased and the fedback current i_{mfa} is decreased. As a result, the output *a* of the amplifier 46 is increased and therefore the output of the function generator 47, namely, the conduction ratio α_m of chopper is increased. When the output *a* of the amplifier 46 reaches the value a_o, the conduction ratio α_m becomes equal to 1, that is, the chopper is always kept in the conductive state. After this time, the output δ of the function generator 48 is decreased, and therefore the actual field current command $i_{fc} \cdot \delta$ is also decreased. As a result, the output α_f of the field control circuit 14 is decreased. Thus, the field-weakening control is conducted in driving the motor at a high speed. As is apparent from the above, a high-speed driving system conducting the field-weakening control can be readily added to the embodiment shown in Fig. 1.

Further, there is a case that a maximum torque is limited in accordance with the angle of accelerator pedal. Fig. 14 shows an example of a circuit arrangement applicable to such a case. The circuit shown in Fig. 14 includes a function generator 50 and a minimum value circuit 51 in addition to the circuit configuration shown in Fig. 13. The output $\alpha_{m\theta}$ of the function generator 50 in increased as the output θ_e of the accelerator unit becomes greater in a range below a predetermined value θ_{eo}. The outputs of the function generators 50 and 47 are applied to the minimum value circuit 51, and therefore the output α_m of the circuit 51 is limited to $\alpha_{m\theta}$ even when the output α_{ma} of the function generator 47 is greater than $\alpha_{m\theta}$. The output characteristic of the function generator 50 which is described above and shown in a block 50, merely shows an example of the function stored in the function generator 50, and any desired function can be readily formed by those skilled in the art. Since the circuit construction of the minimum value circuit 51 is well known in the art, the explanation thereof is omitted for brevity's sake.

The above embodiment can prevent the shunt motor 9 from being driven at a high speed when the accelerator pedal is slightly trodden, and thus can improve a drive feeling of the electromobile.

Fig. 15 shows still another embodiment of an electromobile control device according to the present invention, which employs a microprocessor 60 as a control unit. The blocks indicated by like reference numerals have the same functions as those shown in Figs. 1 and 6. Referring to Fig. 15, the output of an accelerator unit 2 is converted by an analog-digital converter 66 into a digital signal, which is applied to a microprocessor 60. Further, reference numeral 61 designates a random access memory (RAM) for temporarily storing data, 62 a read only memory (ROM) for storing the relation shown in Fig. 2, 63 an ROM for storing the relation shown in Fig. 3 between i_{mc} and τ_{mc}, 64 an ROM for storing the relation shown in Fig. 3 between i_{fc} and τ_{mc}, and 65 and ROM for storing the processing order in the microprocessor 60.

The above embodiment is further provided with such peripheral circuits as a conduction-ratio control oscillator 69 for generating on- and off-pulses of a thyristor chopper in accordance with the conduction-ratio command α_{md} delivered from the microprocessor 60, an analog-digital converted 67 for converting the ouput of an amplifier 15 into a digital signal, another conduction-ratio control oscillator 70 for generating a square wave having a conduction width (or pulse width) in accordance with the conduction-ratio command α_{fd} delivered from the microprocessor 60 to turn on a transistor 29, and another analog-digital converter 68 for converting the output of another amplifier 16 into a digital signal.

Each of the conduction-ratio control oscillators 69 and 70 is made up of only digital elements, as shown in Figs. 16 and 17. In more detail, the conduction-ratio control oscillator 69, as is shown in Fig. 16, includes a register 71, a counter 72, a digital comparator 73, and monostable circuits 74 and 75. The conduction-ratio command α_{md} from the microprocessor 60 is set in the register 71. While, the counter 72 is applied with a pulse train having a predetermined frequency, so that the contents of the counter 72 is repeatedly increased from zero to a maximum value. The output of the digital comparator 73 assumes the level "1" or the level of "0" accordingly as the value set in the register 71 is greater than the contents of the counter 72 or not. Thus, the digital comparator 73 delivers a square wave signal. The square wave signal is applied to the monostable circuits 74 and 75, which deliver an on-pulse synchronized with the rising time of the square wave signal and an off-pulse synchronized with the falling time of the square wave signal, respectively. The on-pulse and the off-pulse form signals for turning on and off the thyristor chopper, respectively.

The conduction-ratio control oscillator 70 shown in Fig. 17 includes a register 76, a counter 77 and a digital comparator 78, and delivers a square wave signal, which has a duty factor corresponding to the conduction-ratio command α_{fd} and forms a signal for controlling the base voltage of the transistor 29.

The ROM 65 stores therein the procedure for processing the contents shown in Figs. 19 to 21. Every processing in the flow chart shown in Fig. 19 is always conducted when no interrupt is generated. That is, the field current command and the armature current command are generated in accordance with the output of the accelerator unit 2. The flow chart in Fig. 20 shows the processing in an interrupt which is carried out at intervals of T_1, that is, the field-current control processing. The flow chart in Fig. 21 shows the processing in another interrupt carried out at intervals of T_o, that is, the armature-current control processing. This processing is conducted in preference to the field-current control processing.

Now, explanation will be made on the control operation by reference to the time chart shown in Fig. 18 and to the flow charts shown in Figs. 19 to 21.

When the microprocessor 60 is supplied with a supply voltage, the processing indicated by the flow chart in Fig. 19 is first conducted. At first, an initial processing is conducted. In this processing, the interrupt is first inhibited, both the armature current command and the field current command are made equal to zero, and then the interrupt inhibit is cancelled. Subsequently, the command generation processing is conducted. That is, the microprocessor 60 takes in the angle θ of accelerator pedal through the analog-digital converter 66, and takes in the contents of the ROM 62 specified by an address corresponding to the above-mentioned θ, that is, a desired torque command τ_{mc}. Next, the microprocessor 60 takes in the contents of each of the ROM's 63 and 64 specified by an address corresponding to the above-mentioned τ_{mc}. The taken-in contents are stored as the armature current command i_{mc} and the field current command i_{fc} in the RAM 61 serving as the working area. In the command generation processing, the above process from the detection of θ to the generation of current command is repeated.

When the interrupt for controlling the field current is generated in the above state, the field current control processing in the flow chart shown in Fig. 20 is carried out. In this processing, the microprocessor

60 takes in the field current value i_{ffd} which is detected by the detector 12 and then amplified by the amplifier 16, through the analog-digital converted 68, subsequently reads out the field current command i_{fc} stored in the RAM 61, and then conducts the following calculation:

$$\alpha_{fd} = k_f(i_{fc} - i_{ffd}) \quad \text{when } i_{fc} \geq i_{ffd}, \qquad \ldots\ldots\ldots \quad (9)$$
$$\alpha_{fd} = 0 \quad \text{when } i_{fc} < i_{ffd}$$

The conduction-ratio command α_{fd} (for the field current chopper) thus obtained is set in the register 76 of the conduction-ratio control oscillator 70. Thus, the oscillator 70 delivers a square wave signal having a conduction ratio of α_f, which controls the transistor 29 through the base drive circuit 20 to pass a desired current through the field winding 10. With the above operation, the field current is made nearly equal to the field current command.

A similar operation is performed in the armature current control system. Since the response of armature current is generally rapid as compared with that of field current, a period T_0 for controlling the armature current is made shorter than a period T_1 for controlling the field current, and the interrupt for armature current control is carried out in preference to that for field current control.

When the interrupt for controlling the armature current is generated, the microprocessor 60 conducts the armature current control processing in the flow chart shown in Fig. 21. The armature current control processing is carried out in the same manner as the field current control processing. That is, the conduction-ratio command α_{md} for the armature current chopper is calculated from the armature current command i_{mc} and the output i_{mfd} of the analog-digital converter 67 by using an equation similar to equation (9), and is set in the register 71 of the conduction-ratio control oscillator 69. Thus, the thyristor chopper 21 repeatedly conducts an on-off operation having a conduction-ratio of α_m to pass an armature current nearly equal to the armature current command i_{mc} through the motor 9.

The embodiment shown in Fig. 15 is simple in construction since the relations shown in Figs. 2 and 3 are merely stored in the ROM's 62 to 64, and moreover can be provided with desired characteristics by using other ROM's in place of the ROM's 62 to 64.

Needless to say, the embodiment shown in Fig. 15 can store various patterns of armature and field currents which have been explained in connection with Fig. 9.

Further, it will be evident to those skilled in the art that the embodiment shown in Fig. 15 can be readily provided with the protective function shown in Fig. 11, the function of conducting the field-weakening control shown in Fig. 13, and the function of controlling the maximum torque shown in Fig. 14.

CLAIMS

1. A control device for an electromobile provided with a shunt motor comprising:

a command means for generating an output torque command of said shunt motor in accordance with an angle of an accelerator pedal trodden;

a pattern generating means for storing, as predetermined patterns, armature and field currents capable of generating an output torque of said shunt motor indicated by said output torque command in such a manner as producing a minimum loss in the driving system of said electromobile, and for generating an armature current command and a field current command in accordance with said predetermined patterns and said output torque command;

armature control means for passing an armature current corresponding to said armature current command through the armature winding of said shunt motor; and

field control means for passing a field current corresponding to said field current command through the field winding of said shunt motor.

2. An electromobile control device according to Claim 1, wherein said pattern generating means includes a function generator for generating said armature current command and a function generator for generating said field current command.

3. An electromobile control device according to Claim 1, wherein said pattern generating means includes a plurality of patterns which are different from each other in dependence upon the number of rotations of said shunt motor.

4. An electromobile control device according to Claim 1 further comprising minimum value means for comparing said armature current command with an armature current limiting signal defined to protect said shunt motor and said control device for said electromobile, and for supplying the smaller of said armature current command and said armature current limiting signal, as said armature current command, to said armature control means.

5. An electromobile control device according to Claim 1 further comprising means for reducing said field current command when a voltage developed across said armature winding of said shunt motor has a maximum value.

6. An electromobile control device according to Claim 1 further comprising:

means applied with an output of an accelerator unit for reducing said output of the accelerator unit and delivering a reduced output signal when said output of said accelerator unit is smaller than a predetermined value; and

minimum value means for comparing the output signal of said means with said armature current command, and for supplying the smaller of said output signal and said armature current command, as said armature current command, to said armature control means.

7. A control device for an electromobile provided with a shunt motor comprising:

a command means for generating an output torque command of said shunt motor in accordance with an angle of an accelerator pedal trodden;

memory means for storing predetermined patterns respectively indicating armature and field currents capable of generating an output torque of said shunt motor indicated by said output torque command in such a manner as producing a minimum loss in the driving system of said electromobile;

a microprocessor for calculating an armature current command and a field current command corresponding respectively to said armature and field currents producing said minimum loss, in a predetermined processing order, on the basis of said output torque command and said predetermined patterns, and for delivering said armature current command and said field current command;

armature control means for passing an armature current corresponding to said armature current command through the armature winding of said shunt motor; and

field control means for passing a field current corresponding to said field current command through the field winding of said shunt motor.

8. An electromobile control device according to Claim 7, wherein said memory means stores a plurality of patterns which are different from each other in dependence upon the number of rotations of said shunt motor.

9. An electromobile control device according to Claim 7, wherein said microprocessor is provided with a function of comparing said armature current command with an armature current limiting signal defined to protect said shunt motor and said control device for said electromobile, and a function of supplying the smaller of said armature current command and said armature current limiting signal, as said armature current command, to said armature control means.

10. An electromobile control device according to Claim 7, wherein said microprocessor is provided with a function of reducing said field current command when a voltage developed across said armature winding of said shunt motor has a maximum value.

11. An electromobile control device according to Claim 7, wherein said microprocessor is provided with a function of producing a reduced signal smaller than an output of an accelerator unit when said output of the accelerator unit is smaller than a predetermined value, a function of comparing said reduced signal with said armature current command, and a function of supplying the smaller of said reduced signal and said armature current command, as said armature current command, to said armature control means.

12. A control device for an electromobile substantially as hereinbefore described with reference to Figures 1 to 8, or Figures 9 and 10, or Figures 11 and 12, or Figure 13, or Figure 14, or Figures 15 to 21 of the accompanying drawings.

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