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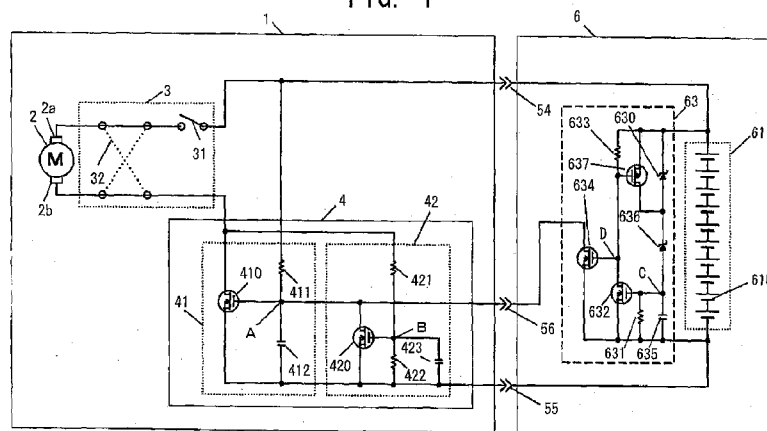
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(54) Title: POWER TOOL AND BATTERY PACK FOR USE THEREIN

FIG. 1



(57) Abstract: A power tool includes a battery pack, a motor, a switching element, a detecting circuit, and a protecting circuit. The battery pack includes a battery. The motor is driven with an electrical power supplied from the battery pack. The switching element is provided between the battery pack and the motor to selectively allow the electrical power to be supplied to the motor when the switching element is turned on and prevent the electrical power from being supplied to the motor when the switching element is turned off. The detecting circuit detects an operating voltage of the switching element. The protecting circuit turns off the switching element when the operating voltage detected by the detecting circuit drops below a first voltage.

DESCRIPTION

[Title of Invention] POWER TOOL AND BATTERY PACK FOR USE THEREIN

[Technical Field]

The present invention relates to a power tool and a battery pack for use therein.

[Background Art]

In recent years, a lithium-ion battery has been extensively used as a power source of a cordless electrical power tool due to a large electrical power supplying capability. If an overdischarge occurs in or an overcurrent flows out of the lithium-ion battery, problems arise, such as shortening of the service life and the danger of accidental ignition. Japanese Unexamined Patent Application Publication No. 2008-062343 discloses a cordless electrical power tool capable of preventing occurrence of overdischarge. To this effect, the cordless electrical power tool is provided with an FET interposed in a current path. A battery pack in which the lithium ion battery is accommodated is provided with a protecting circuit that outputs a halt signal for turning off the FET when the battery voltage has dropped below a lower limit voltage. When the halt signal is not outputted, the battery voltage is applied to the gate of the FET to turn the latter on.

[Prior Art Document]

[Patent Document]

[Patent Document 1] Japanese Unexamined Patent Application Publication No. 2008-062343

[Disclosure of Invention]

[Technical Problem]

Generally, an FET requires to be turned on with a sufficient gate voltage. If the FET is turned on with an insufficient gate voltage, the FET can suffer a high power loss and, in some cases, can be damaged. On the other hands, there is a possibility that a battery pack, for example, a nickel-cadmium battery pack or a nickel-hydrogen battery pack that is not provided with the above protecting circuit is connected to the above cordless electrical power tool. In this case, the battery can continue to supply the electrical power to the cordless electrical power tool, even if the battery voltage drops below the lower limit voltage. As a result, the FET can be turned on with an insufficient gate voltage.

In view of the foregoing, it is an object of the present invention to provide a

power tool and a battery pack capable of preventing a power loss in a switching element such as an FET and a break of the switching element.

[Technical Solution]

5 In order to attain the above and other objects, the invention provides a power tool including a battery pack, a motor, a switching element, a detecting circuit, and a protecting circuit. The battery pack includes a battery. The motor is driven with an electrical power supplied from the battery pack. The switching element is provided between the battery pack and the motor to selectively allow the electrical power to be supplied to the motor when the switching element is turned on and prevent the electrical
10 power from being supplied to the motor when the switching element is turned off. The detecting circuit detects an operating voltage of the switching element. The protecting circuit turns off the switching element when the operating voltage detected by the detecting circuit drops below a first voltage.

15 Another aspect of the present invention provides a battery pack including a battery, a detecting circuit, and a protecting circuit. The battery supplies an electrical power to a motor of a power tool, the power tool including a switching element provided between the battery pack and the motor to selectively allow the electrical power to be supplied to the motor when the switching element is turned on and prevent the electrical power from being supplied to the motor when the switching element is
20 turned off. The detecting circuit detects an operating voltage of the switching element. The protecting circuit turns off the switching element when the operating voltage detected by the detecting circuit drops below a first voltage.

25 Another aspect of the present invention provides a power tool including a body, a motor, a switching element, a detecting circuit, and a protecting circuit. A battery pack including a battery is connectable to the body. The motor is driven with an electrical power supplied from the battery pack. The switching element is provided between the battery pack and the motor to selectively allow the electrical power to be supplied to the motor when the switching element is turned on and prevent the electrical power from being supplied to the motor when the switching element is turned off. The
30 detecting circuit detects an operating voltage of the switching element. The protecting circuit turns off the switching element when the operating voltage detected by the detecting circuit drops below a first voltage.

[Advantageous Effects]

The power tool and the battery pack are capable of preventing a power loss in a switching element such as an FET and a damage of the switching element.

[Brief Description of Drawings]

Fig. 1 is a circuit diagram showing a power tool and a battery pack for use therein according to a preferred embodiment of the present invention;

Fig. 2 is an explanatory diagram showing a relationship between a gate voltage and an on-resistance of an FET; and

Fig. 3 is a circuit diagram showing a power tool and a battery pack according to a variation of the present invention.

[Best Mode for Carrying Out the Invention]

A preferred embodiment of the present invention will be described while referring to Fig. 1. In the following description, the term “power tool” or “electrical power tool” will be used to refer to such a tool that is operable with a battery pack connected thereto. The term “power tool body” will be used to refer to a body of the power tool to which the battery pack is not connected. Further, a variety of switching elements such as a transistor can be adopted as a switching element according to the present invention, although an FET is adopted in the preferred embodiment.

Fig. 1 is a circuit diagram showing a power tool body 1 and a battery pack 6 according to a preferred embodiment of the present invention. While a lithium-ion battery pack is suitable as a power source for the power tool body 1, a nickel-cadmium battery or a nickel-hydrogen battery can also be connected to the power tool body 1. In this embodiment, the nickel-cadmium battery pack or the nickel-hydrogen battery pack will be used in conjunction with the power tool body 1. As shown in Fig. 1, the battery pack 6 can be connected to the power tool body 1 through a positive terminal 54, a negative terminal 55, and a halt signal outputting terminal 56.

The power tool body 1 is provided with a motor 2, a switch unit 3, and a controller 4. The motor 3 is connected between the positive terminal 54 and the negative terminal 55 through the switch unit 3 and controller 4. Specifically, one of a first terminal 2a and a second terminal 2b of the motor 2 is connected to one of the positive terminal 54 and the negative terminal 55, and remaining one of the first terminal and the second terminal is connected to remaining one of the positive terminal 54 and the negative terminal 55. The switch unit 3 includes a trigger switch 31 and a forward-reverse switch 32. The trigger switch 31 is connected to the motor 2 in series,

and is turned on and off in accordance with the user's operation. When the trigger switch 31 is turned on, the motor 2 is driven with an electrical power supplied from the battery pack 6. The forward-reverse switch 32 is a switch for reversing the rotational direction of the motor 2 by switching the connection of the first terminal 2a to the negative terminal 55, and the second terminal 2b to the positive terminal 54. The rotational direction of the motor 2 can be reverted to rotate in the forward direction by switching the connection of the first terminal 2a to the positive terminal 5, and the second terminal 2b to the negative terminal 55.

The controller 4 includes a main current switching circuit 41 and a maintaining circuit 42. The main current switching circuit 41 includes an N-channel field-effect transistor (FET) 410, a resistor 411, and a capacitor 412. The FET 410, the motor 2 and the switch unit 3 are connected in series. Specifically, the drain of the FET 410 is connected to the motor 2, and the source of the FET 410 to the negative terminal 55. The gate of the FET 410 is connected to the halt signal outputting terminal 56. The resistor 411 and the capacitor 412 are connected in series, and a set of the resistor 411 and the capacitor 412 is connected to a set of the motor 2 and the switch unit 3 in parallel. A junction A between the resistor 411 and the capacitor 412 is connected to the gate of the FET 410.

Thus, the battery voltage is applied to the gate of the FET 410. If the battery voltage applied to the gate of the FET 410 exceeds an on-voltage of the FET 410, the FET 410 is turned on. On the other hands, as described later, when the overdischarge occurs, the battery pack 6 outputs a halt signal (0V) to the gate of the FET 410 through the halt signal outputting terminal 56. When the halt signal is applied to the gate of the FET 410, the FET 410 is turned off, resulting in the electrical power supply to the motor 2 being shut off.

Typically, the battery voltage recovers a little after the supply of the electrical power from the battery pack 6 to the motor 2 has been shut off. When the battery voltage recovers and raises above a predetermined voltage, the battery pack 6 stops outputting the halt signal. However, the overdischarge may occur again immediately after the battery pack 6 stops outputting the halt signal. Thus, the supply and the shut-off of the electrical power to the motor 2 can be repeated.

In order to resolve the above problem, the power tool body 1 according to the preferred embodiment is provided with the maintaining circuit 42. The maintaining

circuit 42 includes an N-channel FET 420, resistors 421 and 422, and a capacitor 423. The drain of the FET 420 is connected to the gate of the FET 410 (that is, the junction A), and the source of the FET 410 is connected to the negative terminal 55. The resistors 421 and 422 are connected in series, and a set of the resistors 421 and 422 is connected to the FET 410 in parallel. A junction B between the resistors 421 and 421 is connected to the gate of the FET 420. The capacitor 423 is connected to the resistor 422 in parallel.

When the FET 410 is turned on, a GND level voltage (0V in the preferred embodiment) is applied to the gate of the FET 420 connected to the drain of the FET 410 through the resistor 421. Therefore, when the FET 410 is turned on, the FET 420 is turned off. On the other hand, when the FET 410 is turned off, the battery voltage is applied to the gate of the FET 420 through the motor 2 and the resistor 421. Therefore, when the FET 410 is turned off, the FET 420 is turned on. When the FET 420 is turned on, the gate of the FET 410 is connected to the negative terminal 55 (GND line).

With this construction, once the FET 410 is turned off, the battery voltage of the battery pack 6 is applied to the gate of the FET 420 through the motor 2 and the resistor 421 as long as the trigger switch 31 is turned on. When the battery voltage is applied to the gate of the FET 420, the FET 420 is turned on. When the FET 420 is turned on, the gate of the FET 410 is connected to the negative terminal 55 (GND line). Therefore, once the FET 410 is turned off, the FET 410 keeps an off state as long as the trigger switch 31 is turned on.

Next, the battery pack 6 according to the preferred embodiment will be described while referring to Figs. 1 and 2. The battery pack 6 is provided with a battery 61 and a protecting circuit 63. The battery 61 is composed of a plurality of nickel-cadmium battery cells or a plurality of nickel-hydrogen battery cells 610 that are connected in series.

The protecting circuit 63 includes Zener diodes 630 and 636, resistors 631 and 633, N-channel FETs 632 and 634, P-channel FET 637, and capacitor 635. The Zener diodes 630 and 636 and the resistor 631 are connected in series between the positive terminal 54 and the negative terminal 55. The resistor 633 and the FET 632 are also connected in series between the positive terminal 54 and the negative terminal 55. The gate of the FET 632 is connected to a junction C between the Zener diode 636 and the resistor 631. The capacitor 635 is connected to the resistor 631 in parallel.

The FET 637 is connected to the Zener diode 630 in parallel. Specifically, the source of the FET 637 is connected to the cathode of the Zener diode 630, and the drain of the FET 637 to the anode of the Zener diode 630. The gate of the FET 637 is connected to a junction D between the resistor 633 and the FET 632. The gate of the FET 634 is also connected to the junction D. The drain of the FET 634 is connected to the halt signal outputting terminal 56, and the source of the FET 634 to the negative terminal 55.

Generally, if an FET used as a switching element is turned on with a small gate voltage, heat (power loss) is generated due to the on-resistance of the FET. If the generated heat exceeds a tolerance of the FET, the FET may be damaged. Accordingly, it is preferable to turn on the FET with a sufficiently high-level gate voltage that does not cause the FET to generate heat.

The protecting circuit 63 according to the preferred embodiment outputs a sufficiently high-level voltage as the halt signal to the FET 410 of the power tool body 1 through the halt signal outputting terminal 56 to turn on the FET 410, when the battery voltage (the gate voltage of the FET 410) drops below a halt voltage higher than the overdischarge voltage. Further, the protecting circuit 63 stops outputting the halt signal when the battery voltage (the gate voltage of the FET 410) has recovered and reached a cancel voltage higher than the halt voltage. The Zener diodes 630 and 636 have Zener voltages V_{z1} and V_{z2} , respectively, that are determined based on a nominal battery voltage, the halt voltage, and the cancel voltage.

Fig. 2 is an explanatory diagram showing a relationship between a gate voltage and the on-resistance of an FET. The FET shown in Fig. 2 can be turned on with a gate voltage above an on-voltage 2V. However, when the gate voltage falls within a range of at least 2 to 3 V, the power loss in the FET becomes high due to the high on-resistance. Accordingly, in the example of Fig. 2, it is preferable to set the halt voltage to a voltage higher than at least 3 V capable of greatly reducing the on-resistance. In particular, it is preferable to set the halt voltage to a voltage higher than a voltage corresponding to an inflection point C in Fig. 2 (for example, a voltage represented by the expression $\Delta R/\Delta V \geq -1$). Alternatively, the halt voltage may be set to a voltage corresponding to a steady on-resistance. In the example shown in Fig. 2, at a temperature of 25°C, an on-resistance value is substantially constant in a range where the gate voltage is above 5V, so that the halt voltage may be set to 5 V at the lowest.

On the other hand, the battery voltage of a battery having a nominal battery voltage 12V drastically drops after the battery voltage drops to 8V. Therefore, it is preferable, for the sake of safety of the FET 410, to stop supplying the battery voltage to the gate of the FET 410 when the battery voltage drops to 8V. In order to turn off the FET 410 when the battery voltage drops to 8V, the Zener diode 636 may be selected such that the Zener voltage V_{z2} is 6V. Note that 6V is a value obtained by subtracting on-voltage 2V from the battery voltage 8V.

Further, the battery voltage recovers a little after the supply of the electrical power from the battery pack 6 to the motor 2 has been shut off. When the battery pack 6 according to the preferred embodiment is connected to a conventional electrical power tool, the supply and the shut-off of the electrical power to the motor 2 may be repeated as described above, since the conventional electrical power tool is not provided with the maintaining circuit 42 according to the preferred embodiment. Therefore, in the preferred embodiment, the cancel voltage is set to a voltage higher than the halt voltage. For example, in order to set the cancel voltage to 10 V, 2 V that is obtained by subtracting the halt voltage 8V from the cancel voltage 10 V is determined as the Zener voltage V_{z1} of the Zener diode 630.

When the battery voltage of the battery 61 is higher than the total voltage of the Zener voltage V_{z1} , the Zener voltage V_{z2} , and the on-voltage ($2\text{ V} + 6\text{ V} + 2\text{ V} = 10\text{ V}$ in the above example), the FET 632 is turned on. When the FET 632 is turned on, the gate of the FET 634 is connected to the negative terminal 55 (GND line). Therefore, when the FET 632 is turned on, the FET 634 is turned off. When the FET 634 is turned off, the gate of the FET 410 connected to the drain of the FET 634 through the halt signal outputting terminal 56 is brought to a high impedance state. Thus, when the battery voltage of the battery 61 is higher than the total voltage of the Zener voltage V_{z1} , the Zener voltage V_{z2} , and the on-voltage, the FET 410 is turned on.

The gate of the FET 637 is also connected to the drain of the FET 632. Therefore, when the FET 632 is turned on, the gate voltage of the FET 637 is also connected to the negative terminal 55 (GND line). As a result, the FET 637 is turned on. When the FET 637 is turned on, the Zener voltage V_{z1} of the Zener diode 630 is negated. Therefore, once the FET 632 is turned on, the FET 632 is not turned off until the battery voltage of the battery 61 drops below the halt voltage (the total voltage of the Zener voltage value V_{z2} of the Zener diode 636 and the on-voltage value ($6\text{ V} + 2\text{ V}$

= 8 V)).

When the battery voltage drops below the halt voltage (8 V), the FET 632 is turned off. When the FET 632 is turned off, the battery voltage of the battery 61 is applied to the gate of the FET 634 thorough the resistor 633. As a result, the FET 634 is turned on. When the FET 634 is turned on, the gate of the FET 410 connected to drain of the FET 634 thorough the halt signal outputting terminal 56 is connected to the negative terminal 55 (GND line). Thus, when the battery voltage drops below the halt voltage (8 V), the FET 410 is turned off. As a result, the supply of the electrical power to the motor 2 is shut off.

Moreover, when the FET 632 is turned off, the battery voltage is applied to not only the source of the FET 637 but also the gate of the FET 637. Therefore, when the FET 632 is turned off, the FET 637 is also turned off. Thus, once the FET 632 is turned off, the FET 632 is not turned on until the battery voltage recovers above the cancel voltage (the total voltage of the Zener voltage V_{z1} of the Zener diode 630, the Zener voltage V_{z2} of the Zener diode 636, and the on-voltage ($2\text{ V} + 6\text{ V} + 2\text{ V} = 10\text{ V}$)).

Note that the battery voltage drops temporally and drastically due to a starting current that flows immediately after the trigger switch 31 is turned on. In such case, the FET 632 is turned off due to the drastic drop of the battery voltage. However, in the preferred embodiment, the capacitor 635 is connected between the gate and the source of the FET 632 in order to generate a dead time by absorbing a temporal change of the battery voltage. Therefore, the FET 632 is not turned off with the temporal voltage drop, whereby electrical the power tool can operate stably without being influenced by the starting current.

As described above, in the preferred embodiment, the supply of the electrical power is halted based on the voltage applied to the gate of the FET 410 of the power tool body 1. Accordingly, the FET 410 is not turned on with an insufficient gate voltage, whereby the power loss in the FET 410 and the damage of the FET 410 due to the heat generation can be prevented.

Further, a conventional nickel-cadmium battery pack and a conventional nickel-hydrogen battery pack are not provided with a protecting circuit for preventing the overdischarge or the overcurrent, since the nickel-cadmium battery and the nickel-hydrogen battery do not ignite even if the overdischarge or the overcurrent occurs. Therefore, the nickel-cadmium battery pack and the nickel-hydrogen battery pack can

supply the electrical power to the electrical power tool as long as the battery voltage remains in the battery. However, if the use of empty battery is continued, an inverse charge occurs in the battery, whereby the service life of the battery is considerably shortened. In particular, a high voltage battery composed of a plurality of nickel-cadmium battery cells or a plurality of nickel-hydrogen battery cells, for example, 24
5 volt of battery composed of 20 numbers of 1.2 volt nickel-cadmium battery cells (or nickel-hydrogen battery cells) connected to one another in series, has a high possibility of occurrence of the inverse charge.

However, the battery pack 6 including the nickel-cadmium battery or nickel-hydrogen battery according to the preferred embodiment is provided with the protecting
10 circuit 63 that halts the discharge from the battery when the battery voltage has dropped below the halt voltage. Therefore, the use of the power tool in the overdischarged state is also prevented, so that the service life of the battery 61 can also be prolonged.

Furthermore, it becomes possible to use the nickel-cadmium battery or the
15 nickel-hydrogen battery having a high cost-performance as well as the lithium-ion battery for the cordless power tool body that is suitable to the lithium-ion battery.

While the power tool body 1 and the battery pack 6 according to one embodiment of the invention has been described in detail, it would be apparent to those skilled in the art that various changes and modifications may be made therein without
20 departing from the spirit of the invention.

For example, the protecting circuit 63 is provided in the battery pack 6 in the preferred embodiment. However, as shown in Fig. 3, a protecting circuit 73 may be provided in the power tool body 1 instead of the protecting circuit 63 provided in the battery pack 6. Further, the FET 410 may be provided in the battery pack 6, and the
25 protecting circuit 63 in the power tool body 1. Furthermore, both of them may be provided in the battery pack 6.

Further, a battery other than the nickel-cadmium battery and the nickel-hydrogen battery may be used as the battery 61.

Further, the battery voltage of the battery pack 6 may not necessarily be
30 applied to the gate of the FET 410. Since the battery voltage of the battery pack 6 drops as the power tool is used, it is more effective that the gate voltage of the FET 410 is set to be proportional to the battery voltage of the battery pack 6.

Further, in the preferred embodiment, 8 V that is sufficiently higher than the

gate voltage (2V in the preferred embodiment) with which the FET 410 can be merely turned on is employed as the halt voltage. However, the halt voltage is not limited to 8V.

CLAIMS

1. A power tool comprising:

a battery pack including a battery;

a motor driven with an electrical power supplied from the battery pack;

5 a switching element provided between the battery pack and the motor to selectively allow the electrical power to be supplied to the motor when the switching element is turned on and prevent the electrical power from being supplied to the motor when the switching element is turned off;

a detecting circuit that detects an operating voltage of the switching element;

10 and

a protecting circuit that turns off the switching element when the operating voltage detected by the detecting circuit drops below a first voltage.

2. The power tool according to claim 1, wherein the detecting circuit is configured to absorb a temporal change of the operating voltage.

15 3. The power tool according to claim 1, wherein the protecting unit is configured not to turn on the switching element until the operating voltage recovers above a second voltage higher than the first voltage once the switching element is turned off.

20 4. The power tool according to claim 1, wherein the operating voltage changes in proportion to the battery voltage.

5. The power tool according to claim 1, wherein the battery is one of a nickel-cadmium battery and a nickel-hydrogen battery.

6. The power tool according to claim 1, wherein the switching element is an FET, and the operating voltage is a gate voltage of the FET.

25 7. A battery pack comprising:

a battery that supplies an electrical power to a motor of a power tool, the power tool including a switching element provided between the battery pack and the motor to selectively allow the electrical power to be supplied to the motor when the switching element is turned on and prevent the electrical power from being supplied to the motor when the switching element is turned off;

30

a detecting circuit that detects an operating voltage of the switching element;

and

a protecting circuit that turns off the switching element when the operating

voltage detected by the detecting circuit drops below a first voltage.

8. The battery pack according to claim 7, wherein the detecting circuit is configured to absorb a temporal change of the operating voltage.

9. The battery pack according to claim 7, wherein the protecting unit is configured not to turn on the switching element until the operating voltage recovers above a second voltage higher than the first voltage once the switching element is turned off.

10. The battery pack according to claim 7, wherein the operating voltage changes in proportion to the battery voltage.

11. The battery pack according to claim 7, wherein the battery is one of a nickel-cadmium battery and a nickel-hydrogen battery.

12. The battery pack according to claim 7, wherein the switching element is an FET, and the operating voltage is a gate voltage of the FET.

13. A power tool comprising:

a body to which a battery pack including a battery is connectable;

a motor driven with an electrical power supplied from the battery pack;

a switching element provided between the battery pack and the motor to selectively allow the electrical power to be supplied to the motor when the switching element is turned on and prevent the electrical power from being supplied to the motor when the switching element is turned off;

a detecting circuit that detects an operating voltage of the switching element; and

a protecting circuit that turns off the switching element when the operating voltage detected by the detecting circuit drops below a first voltage.

14. The power tool according to claim 13, wherein the detecting circuit is configured to absorb a temporal change of the operating voltage.

15. The power tool according to claim 13, wherein the protecting unit is configured not to turn on the switching element until the operating voltage recovers above a second voltage higher than the first voltage once the switching element is turned off.

16. The power tool according to claim 13, wherein the operating voltage changes in proportion to the battery voltage.

17. The power tool according to claim 13, wherein the switching element is an

FET, and the operating voltage is a gate voltage of the FET.

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FIG. 1

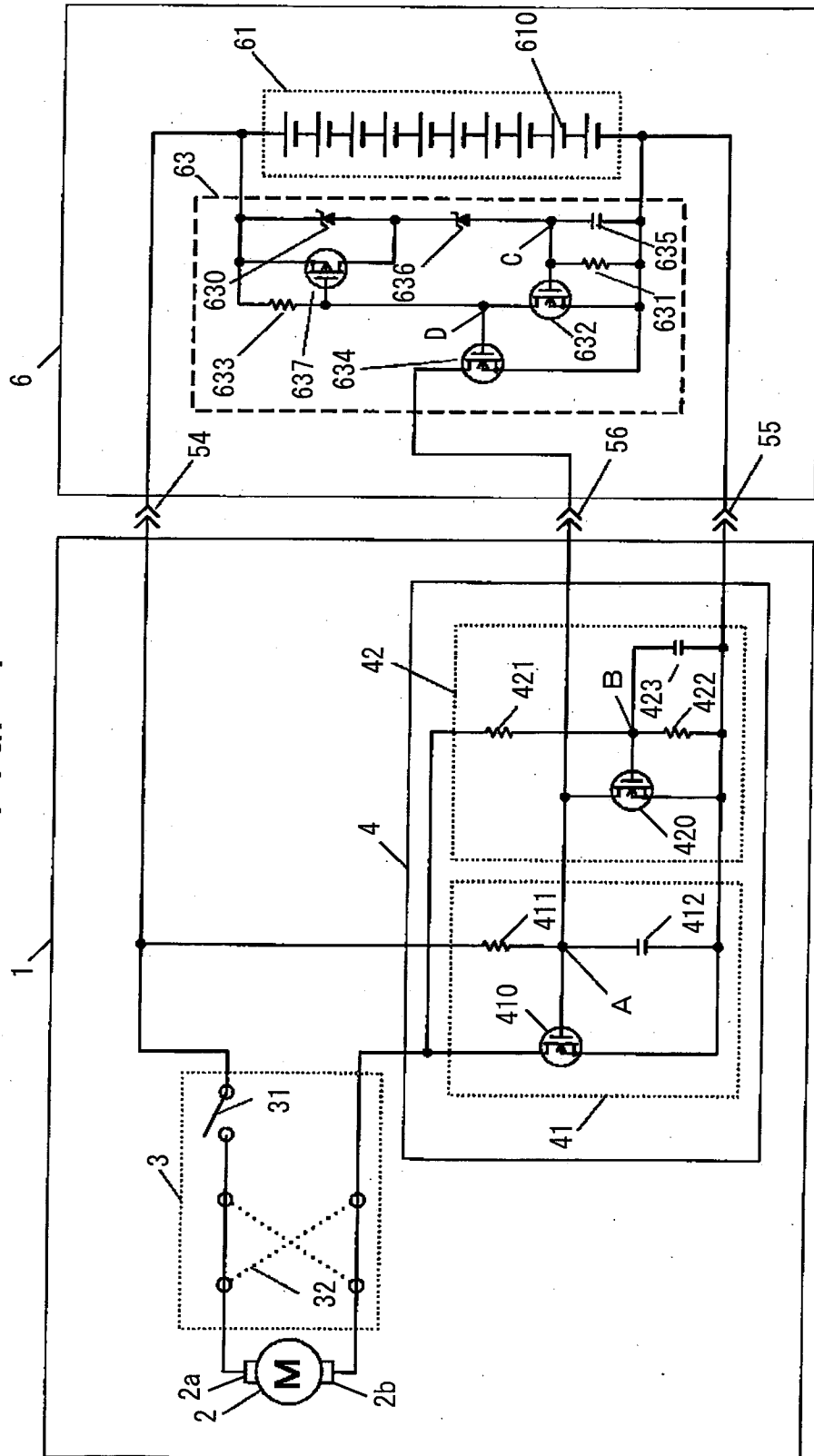


FIG. 2

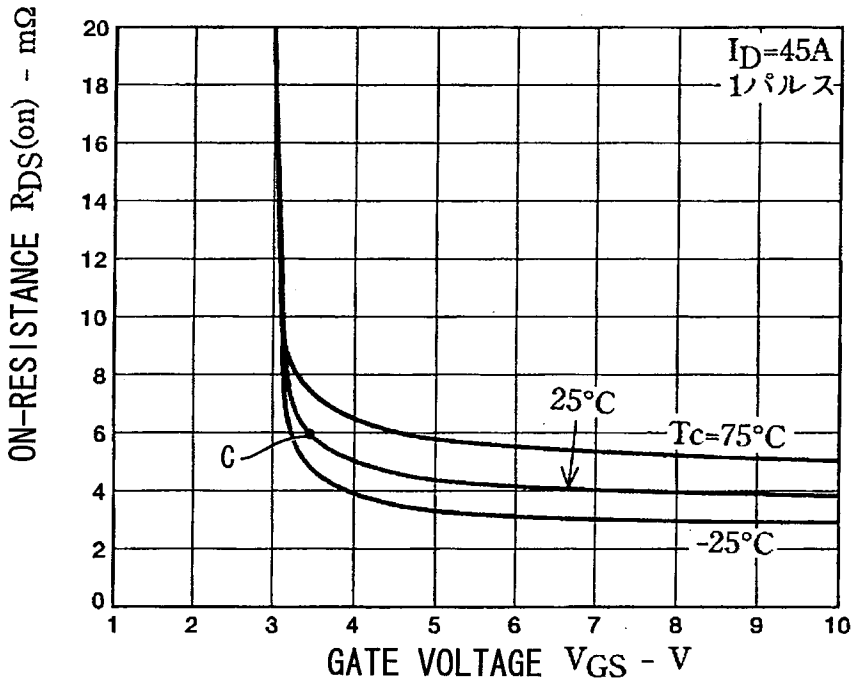
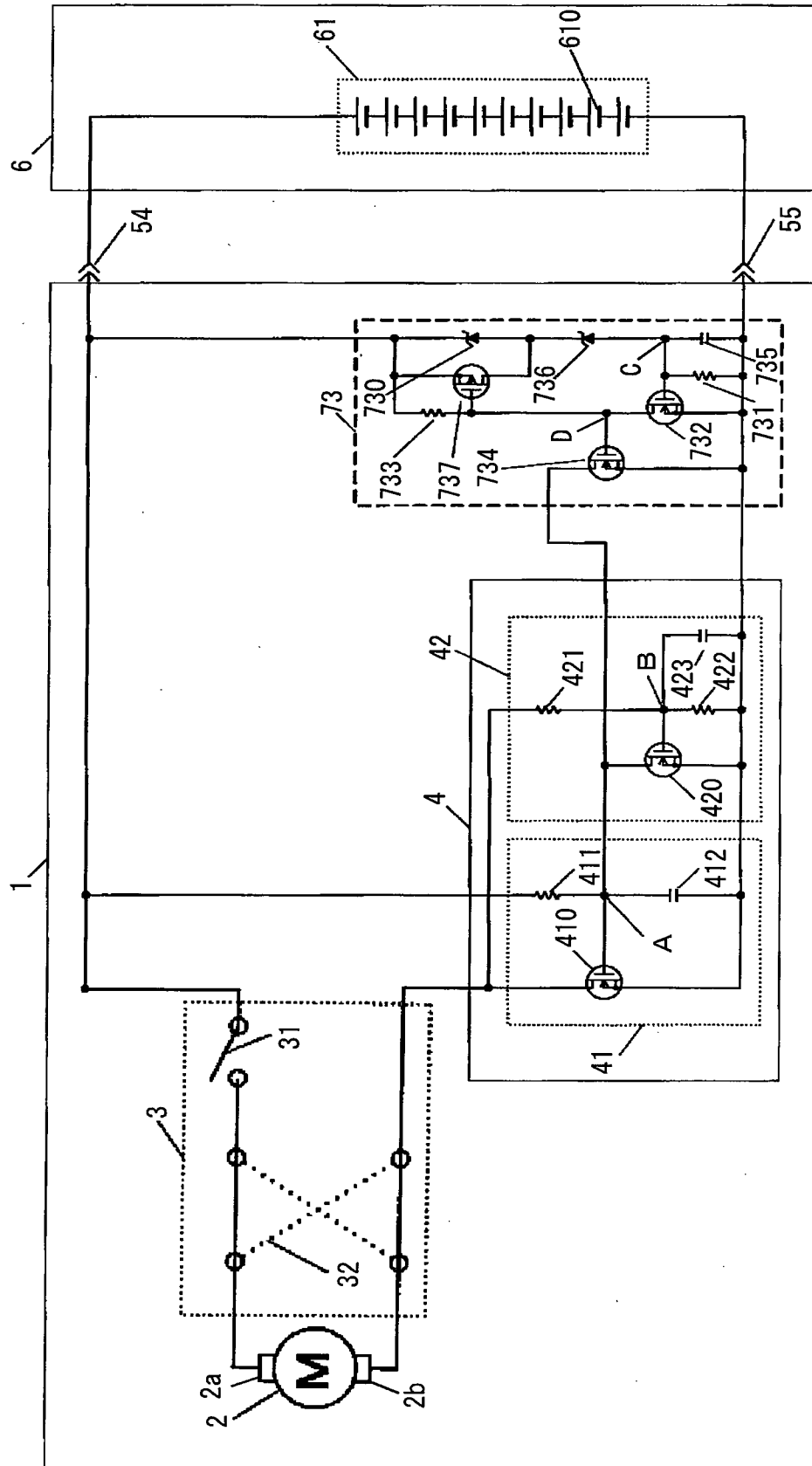


FIG. 3



INTERNATIONAL SEARCH REPORT

International application No
PCT/JP2010/066631

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01M10/48 B25B21/00 G01R31/36
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01M B25B G01R

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 1 897 661 A2 (HITACHI KOKI KK [JP]) 12 March 2008 (2008-03-12) paragraph [0021] - paragraph [0022] paragraph [0024] paragraph [0032] - paragraph [0033] -----	1-17
A	EP 1 890 370 A2 (O2MICRO INC [US]) 20 February 2008 (2008-02-20) the whole document -----	1-17
A	WO 2005/034604 A2 (BLACK & DECKER INC [US]; CARRIER DAVID A [US]; GORTI BHANUPRASAD V [US]) 21 April 2005 (2005-04-21) the whole document -----	1-17

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

☒ See patent family annex.

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Date of the actual completion of the international search

21 December 2010

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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