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(54) **Power tool**

(57) A power tool includes a control unit (23) that controls a gear shift actuator (27) to increase the speed reduction ratio of the power transmission unit (22) as the battery voltage detected by the voltage sensor (S) becomes less than or equal to a predetermined voltage when the speed reduction ratio of the power transmission unit (22) is low. By increasing the speed reduction ratio in this manner, the influence of the internal resistance of a battery pack (12) may be reduced. This allows for the

power tool may to be continuously used and improves the operability. Further, the control unit (23) stops driving the motor (21) as the battery voltage of the battery (12) detected by the voltage sensor (S) becomes less than or equal to a predetermined voltage when the speed reduction ratio of the power transmission unit (22) is relatively high.

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Description

[0001] The present invention relates to a power tool.

[0002] A power tool includes a power transmission unit and a control unit. The power transmission unit reduces the rotation speed of the rotational power obtained from a motor. The control unit controls the power transmission unit and automatically shifts the speed reduction ratio of the power transmission unit (refer to, for example, Japanese Laid-Open Patent Publication No. 11-90845). Such a power tool includes an output shaft and a tip tool (bit), which is coupled to the output shaft. The load torque applied to the output shaft is detected from the load current (drive current) supplied to the motor. The control unit shifts the speed reduction ratio of the power transmission unit based on the detected load torque.

[0003] In the above power tool, it is desirable that over-discharging of a battery pack be obviated. When the output voltage of the battery pack becomes lower than a predetermined value, the motor may be stopped in order to stop discharging of the battery pack.

[0004] However, the battery pack includes internal resistance of the battery cells and resistance between the wires. As the discharge current increases, the internal resistance of the battery cells and resistance between the wires increase the voltage drop. This lowers the virtual battery voltage. Thus, the generation of a discharge current having a large current value, such as current used to start the motor or current used when the motor locks, may cause the voltage of the battery pack to be lower than or equal to the predetermined value and stop the motor even though the actual state of charge of the battery is still sufficient.

[0005] It is an object of the present invention to provide a power tool that improves operability.

[0006] One aspect of the present invention is a power tool including a motor that generates rotational power. A battery supplies the motor with electric power. A voltage sensor detects a battery voltage of the battery. A power transmission unit transmits the rotational power from the motor to an output shaft. The power transmission unit is configured to reduce a rotation speed related to the rotational power and be capable of shifting a speed reduction ratio. A gear shift actuator shifts a speed reduction ratio of the power transmission unit. A torque detector that detects a load torque applied to the output shaft. A control unit controls the gear shift actuator to shift the speed reduction ratio of the power transmission unit in accordance with the detected load torque. When the speed reduction ratio of the power transmission unit is relatively low, the control unit controls the gear shift actuator to increase the speed reduction ratio of the power transmission unit as the battery voltage of the battery detected by the voltage sensor becomes less than or equal to a predetermined voltage. When the speed reduction ratio of the power transmission unit is relatively high, the control unit stops driving the motor as the battery voltage of the battery detected by the voltage sensor be-

comes less than or equal to a predetermined voltage.

[0007] Other aspects and advantages of the present invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

[0008] The invention, together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

Fig. 1 is a schematic diagram of a power tool according to one embodiment of the present invention;

Fig. 2 is a chart illustrating an example of the operation of the power tool shown in Fig. 1;

Fig. 3 is a graph showing the relationship of the internal temperature and internal resistance in a battery pack; and

Fig. 4 is a graph showing the relationship of the torque and current value for different speed reduction ratios.

[0009] One embodiment of a power tool will now be described with reference to the drawings.

[0010] Referring to Fig. 1, the power tool 10 is used as, for example, a drill driver. The power tool 10 includes a main body 11 and a battery pack 12, which is attached to the main body 11 in a removable manner. The main body 11 includes a motor 21, which is driven when supplied with electric power from the battery pack 12, a power transmission unit 22, which reduces the speed of the rotational power from the motor 21, and a control unit 23, which controls the power tool 10. The battery pack 12 includes a rechargeable battery including a plurality of battery cells (e.g., lithium-ion cells). The main body 11 includes a voltage sensor S that detects the battery voltage of the battery pack 12. The voltage sensor S is formed by voltage-dividing resistors. The voltage sensor S supplies the control unit 23 with a voltage corresponding to the divisional voltage ratio of the battery voltage of the battery pack 12.

[0011] The motor 21 includes a rotation shaft 24. The power transmission unit 22, which includes a speed reduction mechanism and a clutch mechanism, is coupled to the rotation shaft 24. The power transmission unit 22 reduces the rotation speed of the rotational power obtained from the motor 21 and transmits the rotational power to the output shaft 25. The power transmission unit 22 includes two gears, namely, an H gear and an L gear. Thus, the speed reduction ratio of the power transmission may be shifted between two stages. A tip tool 26 (bit) is coupled to the tip of the output shaft 25. Accordingly, the power tool 10 is configured to rotate the tip tool 26 together with the output shaft 25 by transmitting rotational power from the motor 21 via the power transmission unit 22 to the output shaft 25. The power transmission unit 22 is set so that the speed reduction ratio of the L gear

is greater than the speed reduction ratio of the H gear. Thus, the L gear allows for low speed rotation with a high torque.

[0012] The power transmission unit 22 includes a gear shift actuator 27. The gear shift actuator 27, which may be a motor actuator, shifts the speed reduction ratio of the power transmission unit 22. The control unit 23 controls a gear shift driver 28 to supply the gear shift actuator 27 with a certain amount of drive power. The gear shift actuator 27 is operated by the drive power supplied from the gear shift driver 28. Accordingly, the gear shift actuator 27 shifts the gears of the power transmission unit 22 under the control of the control unit 23 via the gear shift driver 28. The control unit 23 runs on voltage-regulated electric power supplied from the battery pack 12. The gear shift driver 28 is formed by, for example, an H-bridge circuit using a switching element (e.g., FET). The control unit 23 provides the gear shift driver 28 with a control signal. The gear shift driver 28 changes the rotational direction of the motor and performs PWM control to supply the gear shift actuator 27 with drive power.

[0013] The main body 11 of the power tool 10 includes a switching drive circuit 29 formed by, for example, an H-bridge circuit using a switching element (e.g., FET). The switching drive circuit 29 supplies the motor 21 with drive power. The motor 21 generates rotation based on the drive power from the switching drive circuit 29. The control unit 23 controls the switching drive circuit and performs PWM control on the electric power from the battery pack 12 to supply the motor 21 with drive power. In other words, the control unit 23 controls the electric power supplied to the motor 21 via the switching drive circuit 29. This controls the rotation speed of the motor 21.

[0014] The main body 11 of the power tool 10 includes a trigger switch 31 that may be operated by a user. The trigger switch 31, which is activated and deactivated by the user, starts and stops the motor 21. Further, the trigger switch 31 provides the control unit 23 with an output signal that is in accordance with the operation amount of the trigger switch 31 (pulled amount of trigger). The control unit 23 controls the electric power supplied to the motor 21 by the switching drive circuit 29 based on the output signal from the trigger switch 31 to start and stop the motor 21 and adjust the rotation speed of the motor 21.

[0015] The main body 11 of the power tool 10 includes a current detector 41 arranged between the switching drive circuit 29 and the motor 21 to detect the load current (drive current) supplied to the motor 21. The current detector 41 includes a detection resistor 42 and an amplification circuit 43 (operational amplifier). The detection resistor 42 is connected between the switching drive circuit 29 and the motor 21. The amplification circuit 43 amplifies the voltage across the terminals of the detection resistor 42 to generate a detection signal provided to the control unit 23. The control unit 23 detects the load current based on detection signals from the current detector 41 taken in predetermined sampling cycles. Further, the

control unit 23 detects the load torque applied to the output shaft 25 (tip tool 26) based on the detected load current and the gear to which the power transmission unit 22 is shifted when the load current is detected. The control unit 23 detects locking of the motor 21 based on the detected load torque and controls the motor 21 in accordance with the detection.

[0016] In the power tool 10, the control unit 23 controls the gear shift actuator 27 and automatically shifts the gears of the power transmission unit 22 based on the detected load torque. The speed reduction mechanism of the power transmission unit 22 is, for example, a planetary gear speed reduction mechanism. The speed reduction mechanism of the power transmission unit 22 includes a sun gear rotated about the axis of the rotation shaft 24 of the motor 21, planet gears engaged with the sun gear, and a ring gear engaged with the planet gear. The gear shift actuator 27 moves the ring gear to change the planet gear engaged with the ring gear. This controls the gear of the power transmission unit 22. The main body 11 of the power tool 10 may include a drive state detector that detects whether or not the gear shift actuator 27 has moved the ring gear to the correct position and provides the control unit 23 with a corresponding detection signal. In such a case, the control unit 23 would control the gear shift actuator 27 based on the detection signal of the drive state actuator.

[0017] In the power tool 10, when the user pulls the trigger switch 31, the control unit 23 is provided with an output signal that is in accordance with the pulled amount. The control unit 23 controls the switching drive circuit 29 based on the output signal from the trigger switch 31 to start and stop the motor 21 and control the rotation speed of the motor 21. The power transmission unit 22 transmits the rotational power of the motor 21 to the output shaft 25 and rotates the tip tool 26. The control unit 23 shifts the gears of the power transmission unit 22 to the H gear or the L gear in accordance with the load torque. More specifically, the H gear is selected in the power transmission unit 22 when the load torque is small to drive the tip tool 26 at a high rotation speed with a small torque. When the power tool 10 is activated, the H gear is selected in the power transmission tool. When the load torque increases and exceeds a predetermined torque, the L gear is selected in the power transmission unit 22. Further, the control unit 23 detects locking of the motor 21 based on the detection signal from the current detector 41 and stops the motor 21. When the L gear is selected, the control unit 23 detects locking of the motor 21 based on the load torque (current) detected by the current detector 41 and time elements. Further, the power tool 10 detects the battery voltage of the battery pack 12 with the voltage sensor S and shifts the power transmission unit 22 from the H gear to the L gear in accordance with the detected battery voltage.

[0018] An example of the operation of the power tool 10 based on the battery voltage will now be described with reference to Figs. 1 and 2.

[0019] Referring to Fig. 2, at time t1, when a user pulls and activates the trigger switch 31, the control unit 23 drives the motor 21 with the switching drive circuit 29. Here, the power transmission unit 22 is shifted to the H gear, which has a relatively low speed reduction ratio. The power transmission unit 22 includes a plurality of (two in the present embodiment) speed reduction ratios, and the relatively low speed reduction ratio refers to the smaller one of the speed reduction ratios.

[0020] At time t2, when an inrush current flows to the motor 21, the battery voltage of the battery pack 12 measured by the voltage sensor S becomes less than or equal to a predetermined voltage V1, and the control unit 23 stops the motor 21 with the switching drive circuit 29.

[0021] From time t2 to time t3, the control unit 23 controls the gear shift actuator 27 with the gear shift driver 28 to shift the power transmission unit 22 from the H gear to the L gear, which has a relatively high speed reduction ratio. Referring to Fig. 3, chemical reactions become slow when the temperature is low. This increases the internal resistance of the battery pack 12. Accordingly, when current flows to the battery cell at a low temperature, the voltage drop in the battery cell becomes greater than when the temperature is high. Further, referring to Fig. 4, when the torque is the same, the motor current increases as the speed reduction ratio decreases, and the motor current decreases as the speed reduction ratio increases. Thus, even when the battery voltage is less than or equal to the predetermined voltage V1, the speed reduction ratio may be increased to decrease the motor current and thereby reduce the influence of the internal resistance of the battery pack 12. This allows for the user to use the power tool 10 without performing any special tasks under conditions in which the power tool 10 could not be used in the prior art.

[0022] The control unit 23 shifts the power transmission unit 22 to the L gear. At time t5, due to an inrush current that flows to the motor 21, the voltage sensor S detects that the battery voltage of the battery pack 12 is less than or equal to the predetermined voltage. Based on the detection of the voltage sensor S, the control unit 23 stops the motor 21 with the switching drive circuit 29.

[0023] The advantages of the present embodiment will now be described.

(1) When the power transmission unit 22 has a small speed reduction ratio and the battery voltage detected by the voltage sensor S becomes less than or equal to the predetermined voltage V1, the control unit 23 controls the gear shift actuator 27 so that the speed reduction ratio of the power transmission unit 22 is relatively high. This reduces the influence of internal resistance of the battery pack 12. Thus, the user may continuously use the power tool 10. This improves the operability of the power tool 10. Further, when the power transmission unit 22 has a high speed reduction ratio and the battery voltage detected by the voltage sensor S becomes less than or

equal to the predetermined voltage V1, the control unit 23 stops driving the motor 21. This allows for over-discharging of the battery pack 12 to be obviated.

[0024] It should be apparent to those skilled in the art that the present invention may be embodied in many other specific forms without departing from the spirit or scope of the invention. Particularly, it should be understood that the present invention may be embodied in the following forms.

[0025] In the above embodiment, the temperature of the battery pack 12 may be detected, and the control illustrated in Fig. 2 may be performed only when the detected temperature is low and less than or equal to a predetermined temperature X. This is because the internal resistance of the battery pack 12 increases when the battery pack 12 has a low internal temperature, and the battery voltage easily becomes less than or equal to the predetermined voltage V1 when the temperature of the battery pack 12 is low. When the battery pack 12 is a lithium-ion battery, the predetermined temperature may be set to about 5°C although there is no limitation to such a temperature.

[0026] In the above embodiment, as shown in Fig. 1, a rotation detector 51 may be used to detect locking of the motor 21 based on the rotation speed of the motor 21. The rotation detector 51 may be arranged on the rotation shaft 24 of the motor 21. The rotation detector 51 includes a sensor magnet 52, which is provided with magnetic poles fixed to and rotated integrally with the rotation shaft 24, and a Hall element 53, which is arranged opposing the sensor magnet 52. The Hall element 53 provides the control unit 23 with a detection signal indicating changes in the magnetic flux based on the rotation of the sensor magnet 52. The control unit 23 detects the rotation speed of the motor 21 based on the detection signal from the rotation detector 51. The control unit 23 also detects locking of the motor 21 from changes in the rotation speed. More specifically, the control unit 23 detects locking of the motor 21 from the rotation speed of the motor 21 detected by the rotation detector 51. When locking occurs in the motor 21, the rotation speed of the motor 21 suddenly decreases. Accordingly, the control unit 23 is configured to detect locking of the motor 21 based on both load torque T and rotation speed. For example, the control unit 23 determines that locking of the motor 21 is not occurring even when the load torque T exceeds a lock detection threshold as long as the rotation speed does not decrease or the decreasing rate of the rotation speed is low. This increases the accuracy for detecting the locking of the motor 21.

[0027] In the above embodiment, locking detection is performed on the motor 21. However, locking detection does not have to be performed on the motor 21.

[0028] In the above embodiment, the load torque T is indirectly detected from the load current supplied to the motor 21. Instead, the torque applied to the output shaft

25 may be directly measured.

[0029] In the above embodiment, the power transmission unit 22 shifts two gears. Instead, the power transmission unit 22 may shift three or more gears. When shifting three speed reduction gears, if the gear having the smallest speed reduction ratio is selected and the battery voltage becomes less than or equal to the predetermined value V1, the control unit 23 controls the gear shift actuator 27 and shifts the power transmission unit 22 to, for example, the gear having the speed reduction ratio that is second to the largest. In this case, when the battery voltage becomes less than or equal to the predetermined value V1, the control unit 23 controls the gear shift actuator 27 and shifts the power transmission unit 22 to, for example, the gear having the largest speed reduction ratio. In this manner, by gradually increasing the speed reduction ratio, the influence of the internal resistance of the battery pack 12 may be reduced. This allows for the user to continuously use the power tool 10 and improve the operability of the power tool 10.

[0030] For example, when the power transmission unit 22 has the largest speed reduction ratio and the battery voltage detected by the voltage sensor S becomes less than or equal to the predetermined voltage V1, the control unit 23 stops driving the motor 21. This allows for over-discharging of the battery pack 12 to be obviated.

[0031] In the above embodiment, the gear shift actuator 27 includes a motor actuator. However, the gear shift actuator 27 does not have to use a motor as a drive source and may use a solenoid or the like instead.

[0032] In the above embodiment, the power tool 10 is embodied in a drill driver but may be embodied in a different type of power tool such as an impact driver, an impact wrench, a hammer drill, a vibration drill, a jigsaw, and a sealing gun.

[0033] The present examples and embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.

Claims

1. A power tool (10) including:

a motor (21) that generates rotational power;
a battery (12) that supplies the motor (21) with electric power;
a voltage sensor (S) that detects a battery voltage of the battery (12);
a power transmission unit (22) that transmits the rotational power from the motor (21) to an output shaft (25), wherein the power transmission unit (22) is configured to reduce a rotation speed related to the rotational power and be capable of shifting a speed reduction ratio;
a gear shift actuator (27) that shifts a speed re-

duction ratio of the power transmission unit (22);
a torque detector (41) that detects a load torque applied to the output shaft (25); and
a control unit (23) that controls the gear shift actuator (27) to shift the speed reduction ratio of the power transmission unit (22) in accordance with the detected load torque,
the power tool being **characterized in that:**

when the speed reduction ratio of the power transmission unit (22) is relatively low, the control unit (23) controls the gear shift actuator (27) to increase the speed reduction ratio of the power transmission unit (22) as the battery voltage of the battery (12) detected by the voltage sensor (S) becomes less than or equal to a predetermined voltage; and

when the speed reduction ratio of the power transmission unit (22) is relatively high, the control unit (23) stops driving the motor (21) as the battery voltage of the battery (12) detected by the voltage sensor (S) becomes less than or equal to a predetermined voltage.

2. The power tool according to claim 1, being **characterized in that:**

the control unit (23) determines whether or not the temperature of the battery (12) is less than or equal to a predetermined temperature; and
when the speed reduction ratio of the power transmission unit (22) is relatively low, the control unit (23) controls the gear shift actuator (27) to increase the speed reduction ratio of the power transmission unit (22) if the battery voltage of the battery (12) becomes less than or equal to the predetermined voltage and the control unit (23) determines that the temperature of the battery (12) is less than or equal to the predetermined temperature.

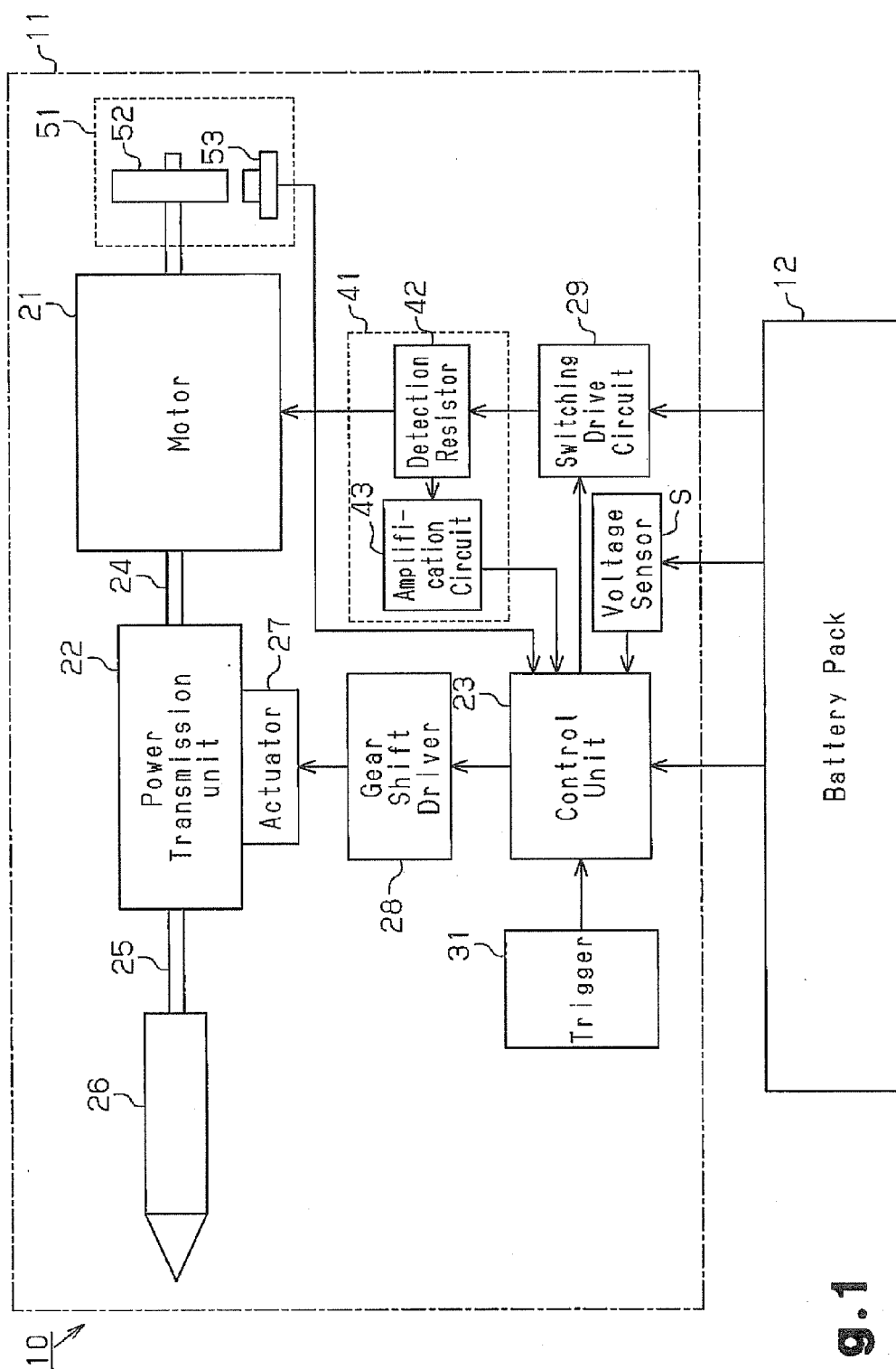


Fig.1

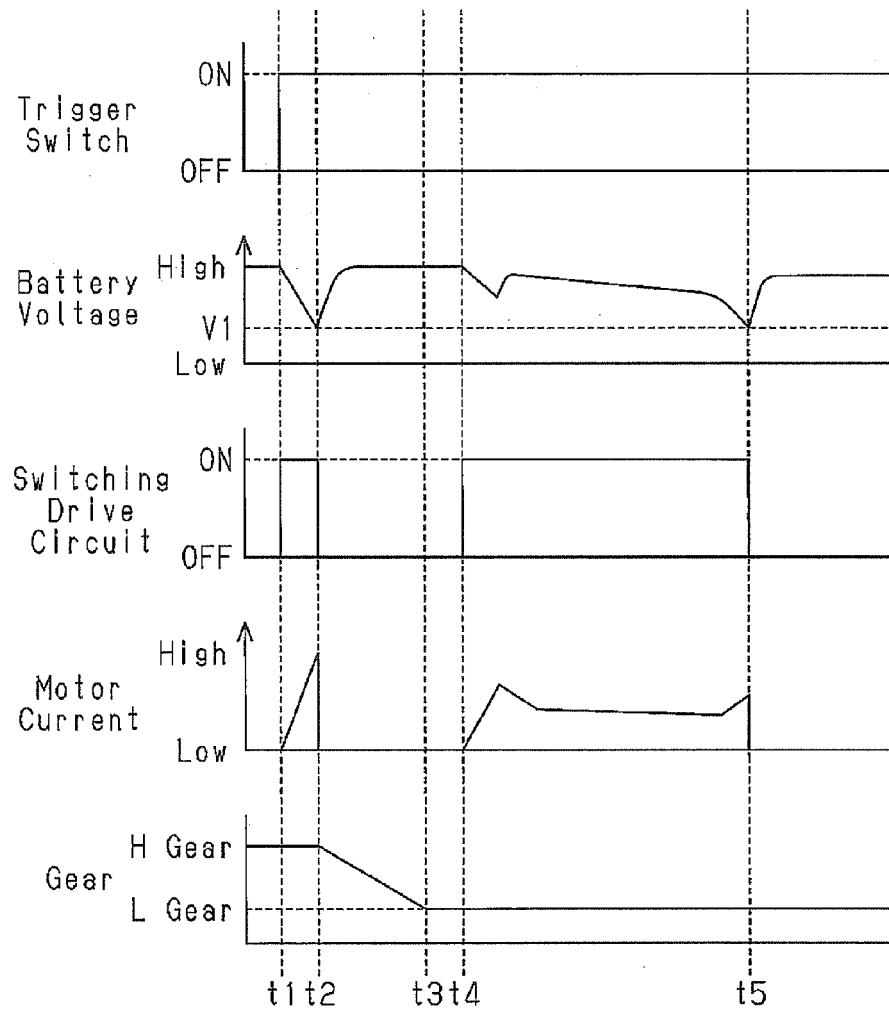
Fig.2

Fig.3

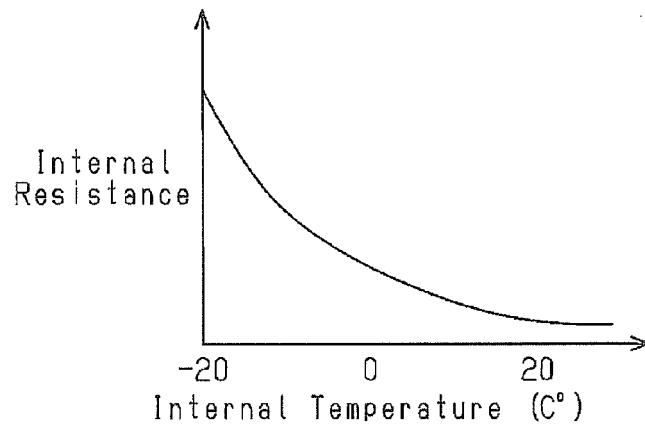
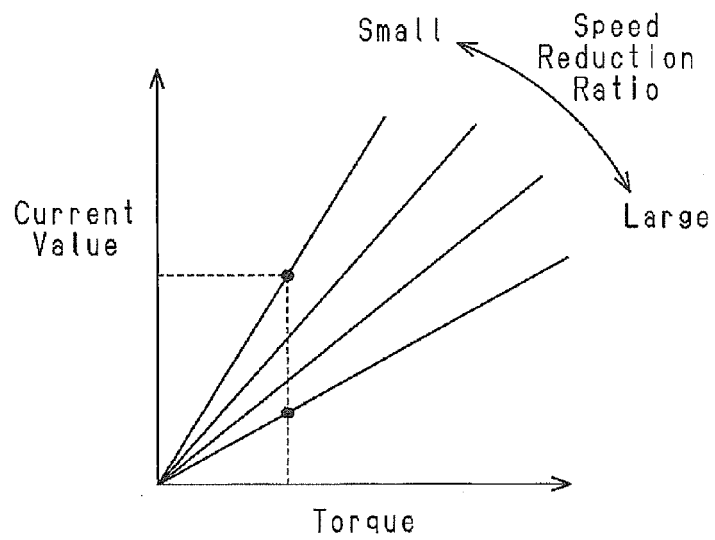


Fig.4





EUROPEAN SEARCH REPORT

Application Number
EP 13 18 3832

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A,D	JP H11 90845 A (MATSUSHITA ELECTRIC WORKS LTD) 6 April 1999 (1999-04-06) * the whole document *	1,2	INV. B25F5/00
A	WO 2012/114815 A1 (PANASONIC ECO SOLUTIONS POWER TOOLS CO LTD [JP]; ATSUMI MASATOSHI; INA) 30 August 2012 (2012-08-30) * the whole document *	1,2	
			TECHNICAL FIELDS SEARCHED (IPC)
			B25F
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 6 March 2014	Examiner Gavaza, Bogdan
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 13 18 3832

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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06-03-2014

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