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(54) **BATTERY CHARGER AND BATTERY CHARGING METHOD**

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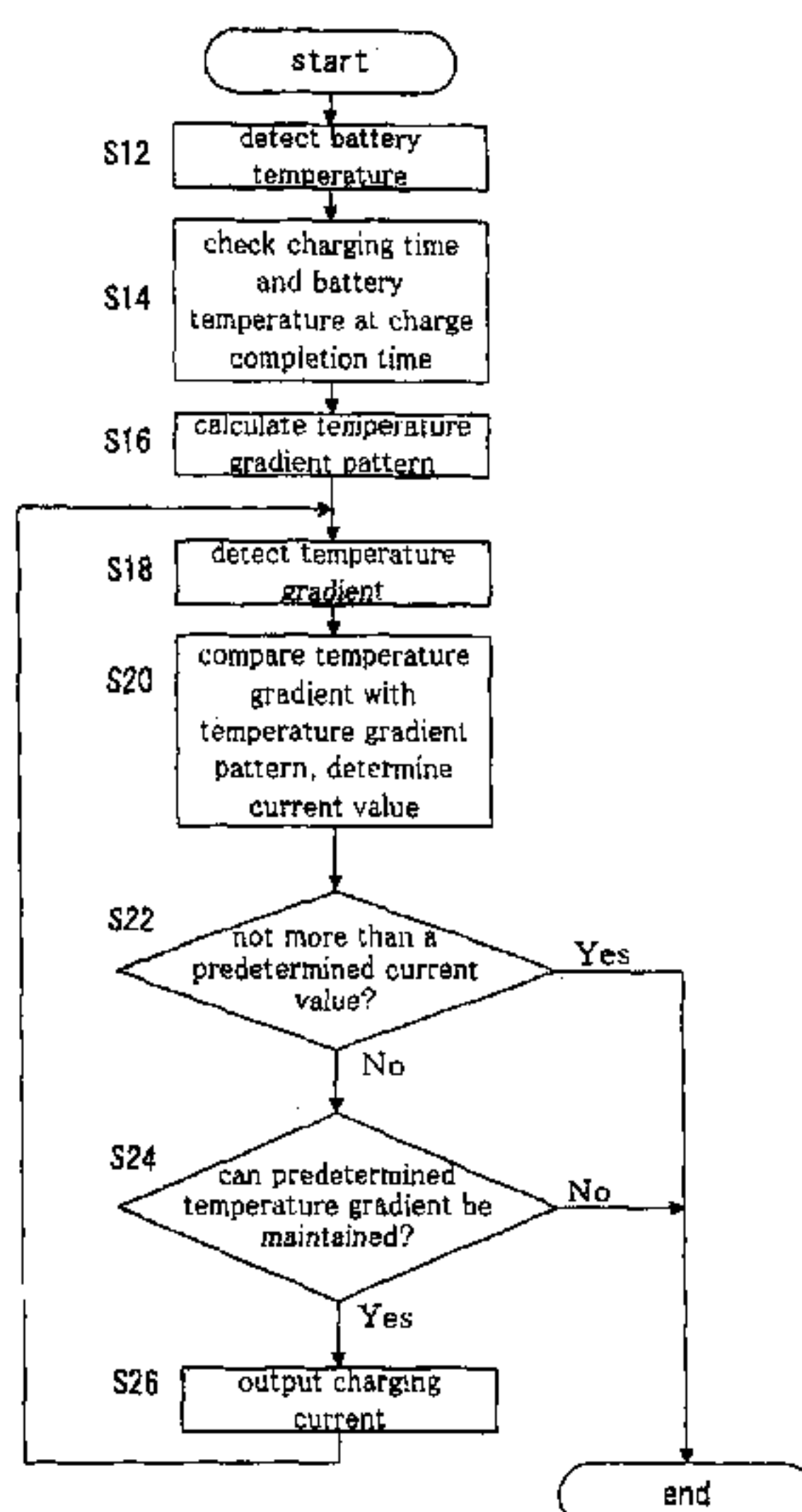
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(57) **ABSTRACT**

A temperature rise pattern is retrieved from charging time based on the difference between a battery temperature at the beginning of battery charge and a target temperature value which a battery is intended to reach (in S116). The battery is charged while adjusting a current value so that a temperature rise value becomes the temperature rise pattern (in S118 and S120). Thus, by optimizing the temperature rise pattern, it is possible to charge the battery so that the temperature at the time of the completion of battery charge becomes the target temperature value (the lowest temperature value).

47 Claims, 15 Drawing Sheets



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Fig. 1

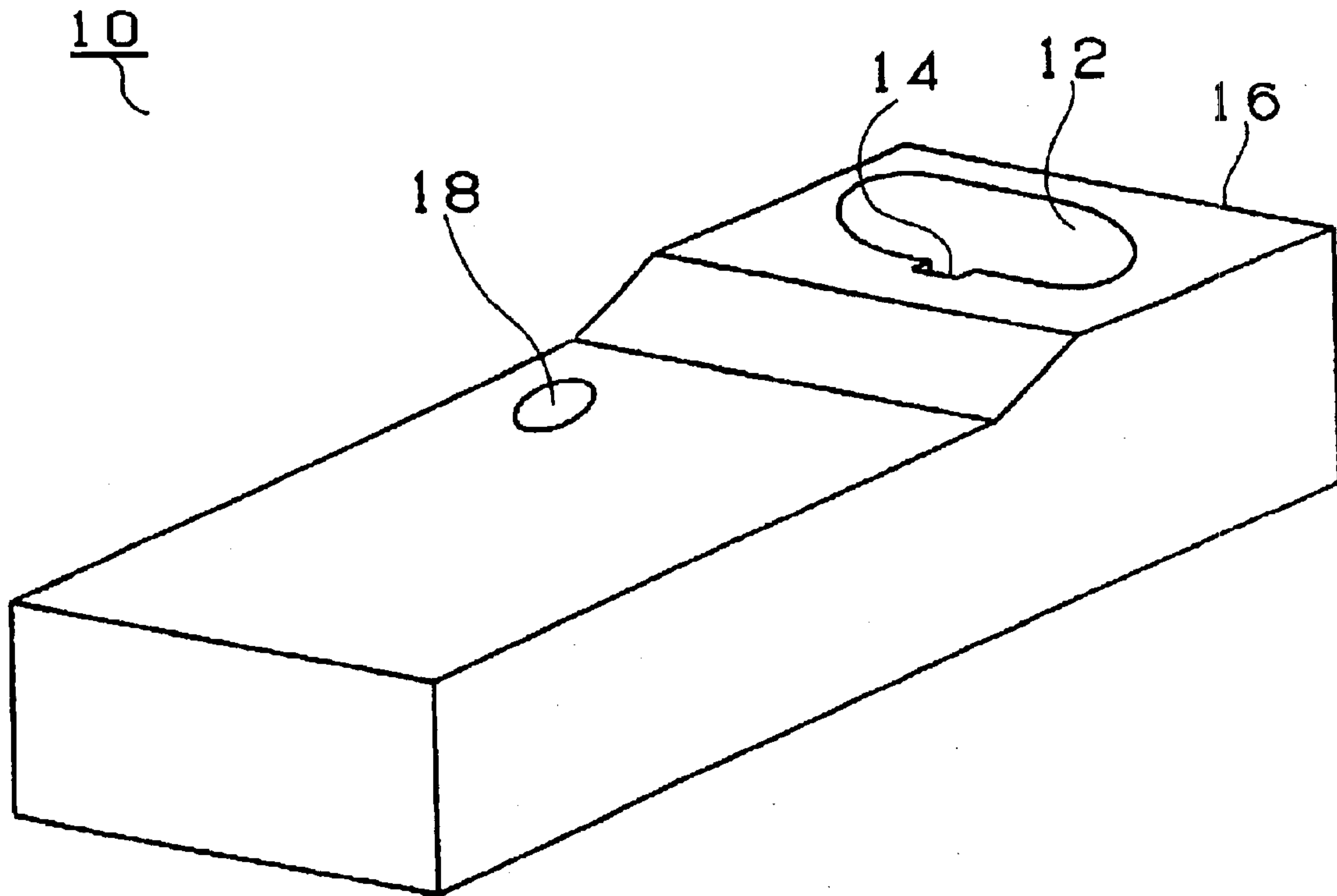


Fig. 2

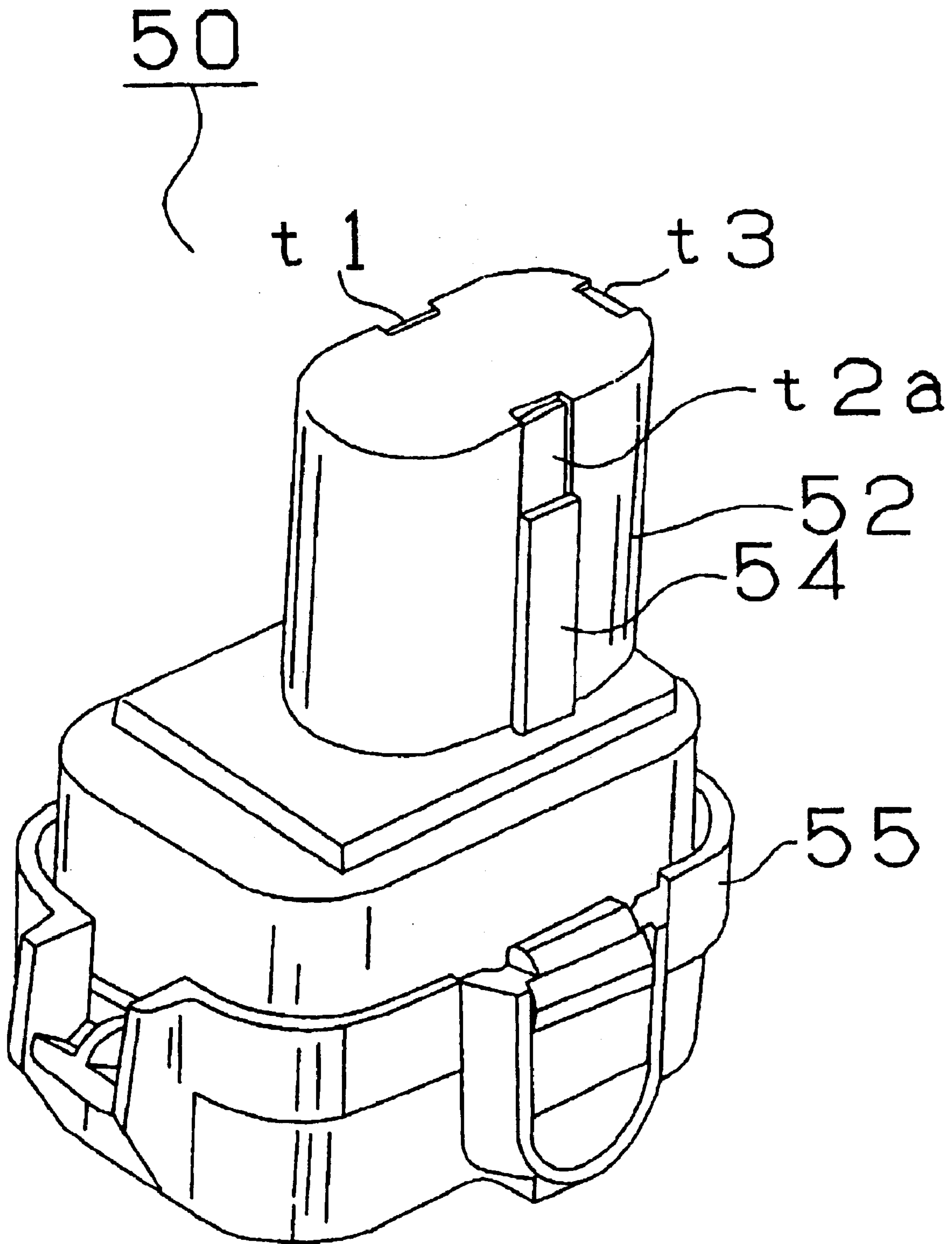


Fig. 3

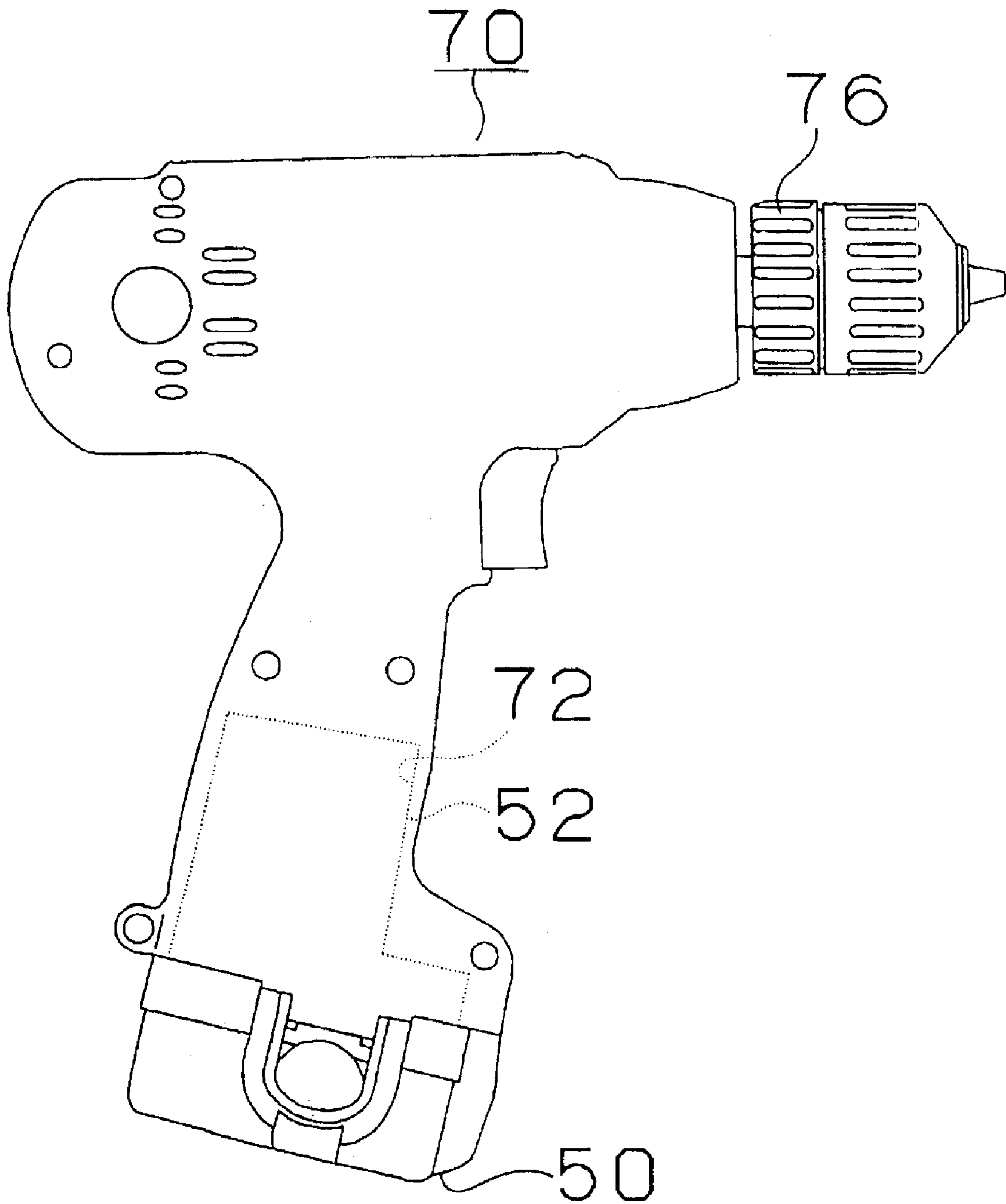
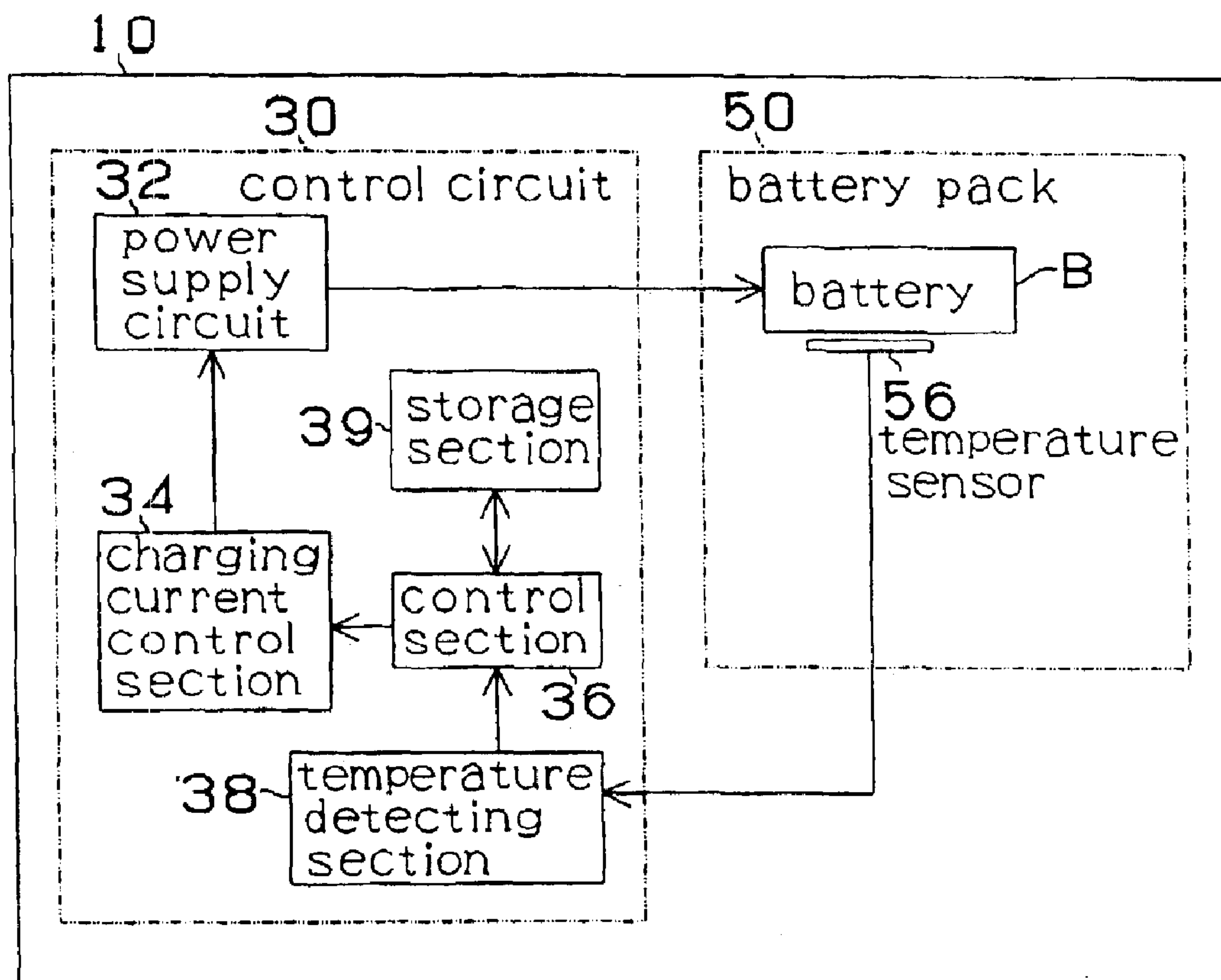


Fig. 4



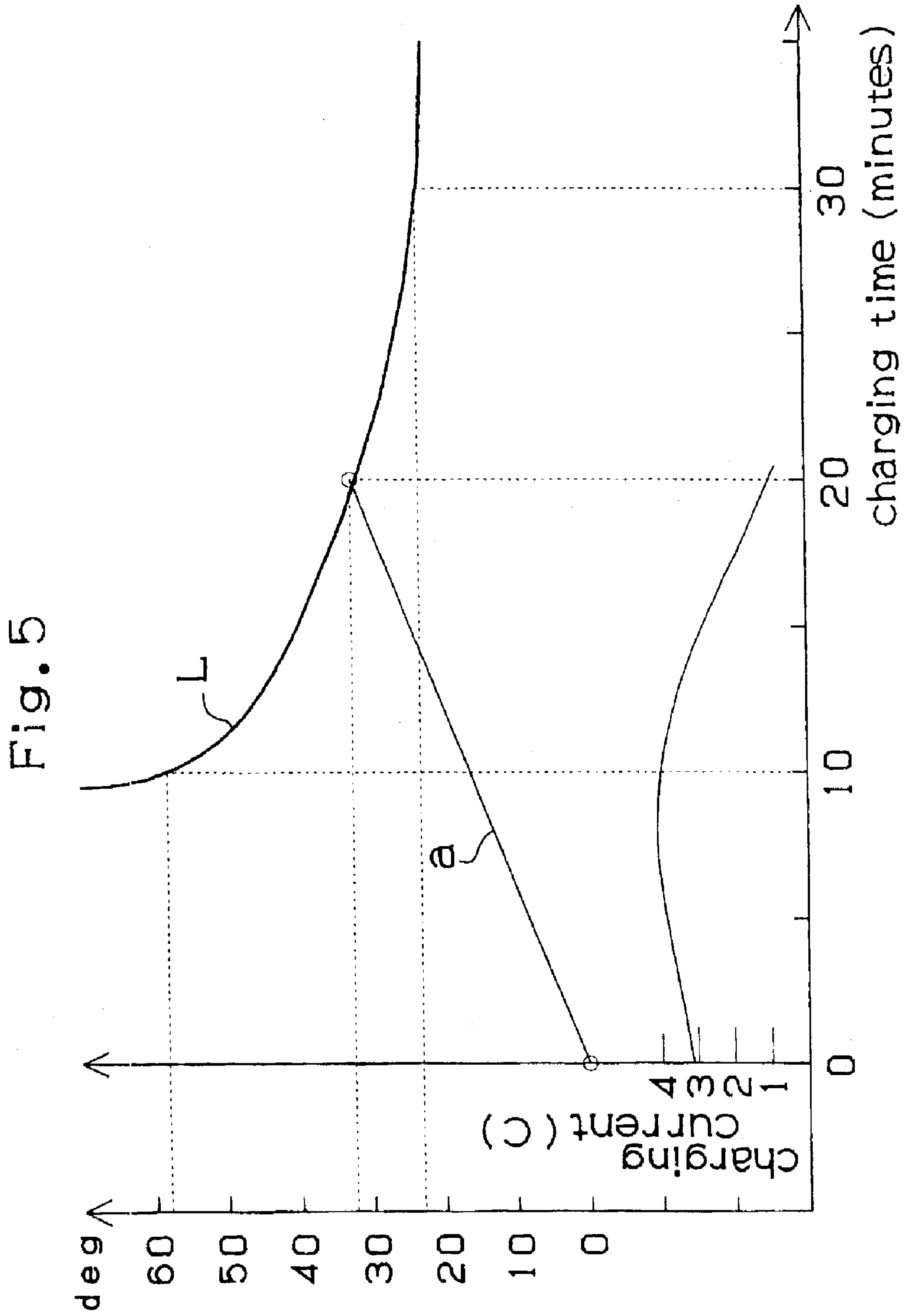


FIG. 6

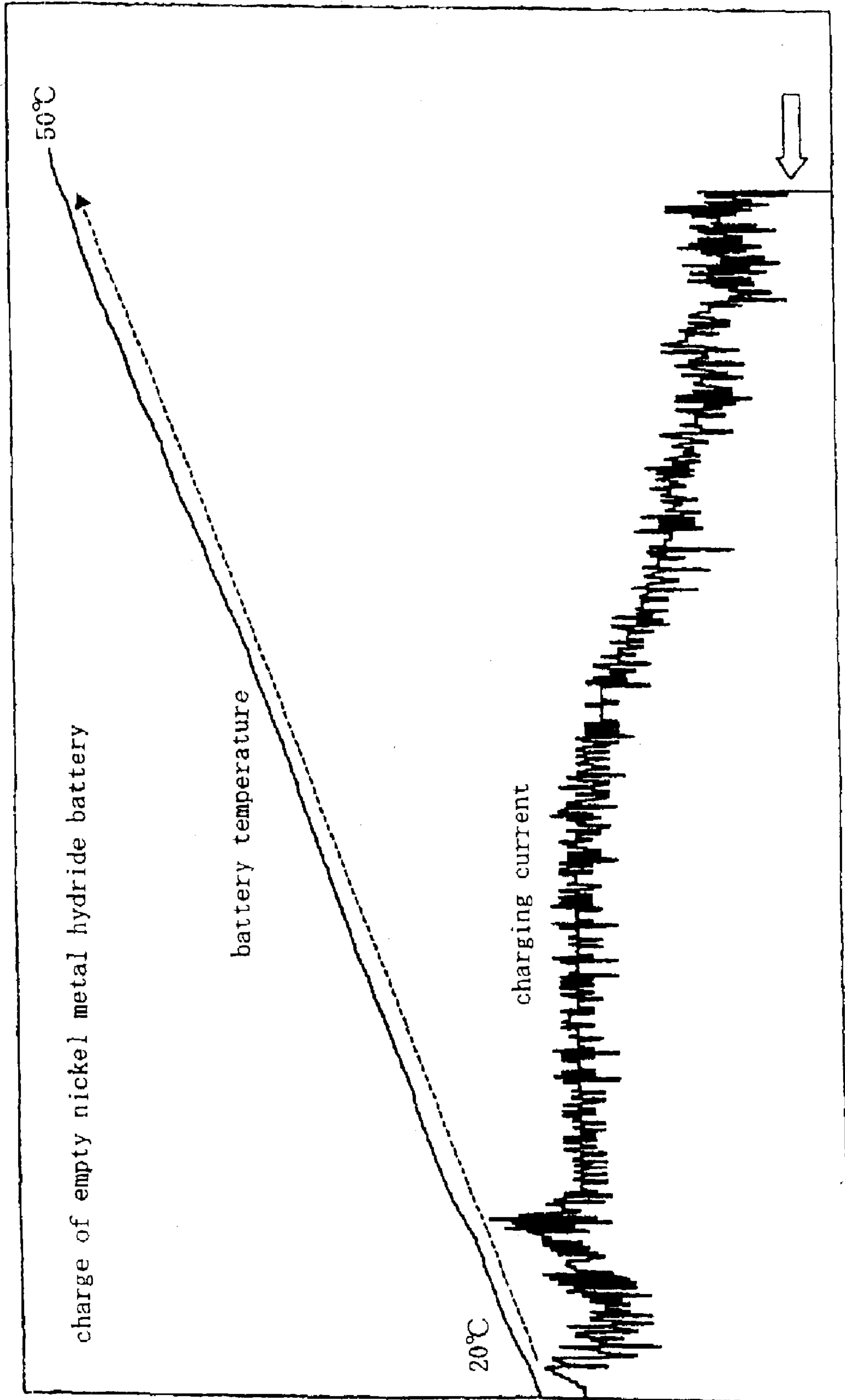


FIG. 7

charge of almost fully charged nickel metal hydride battery

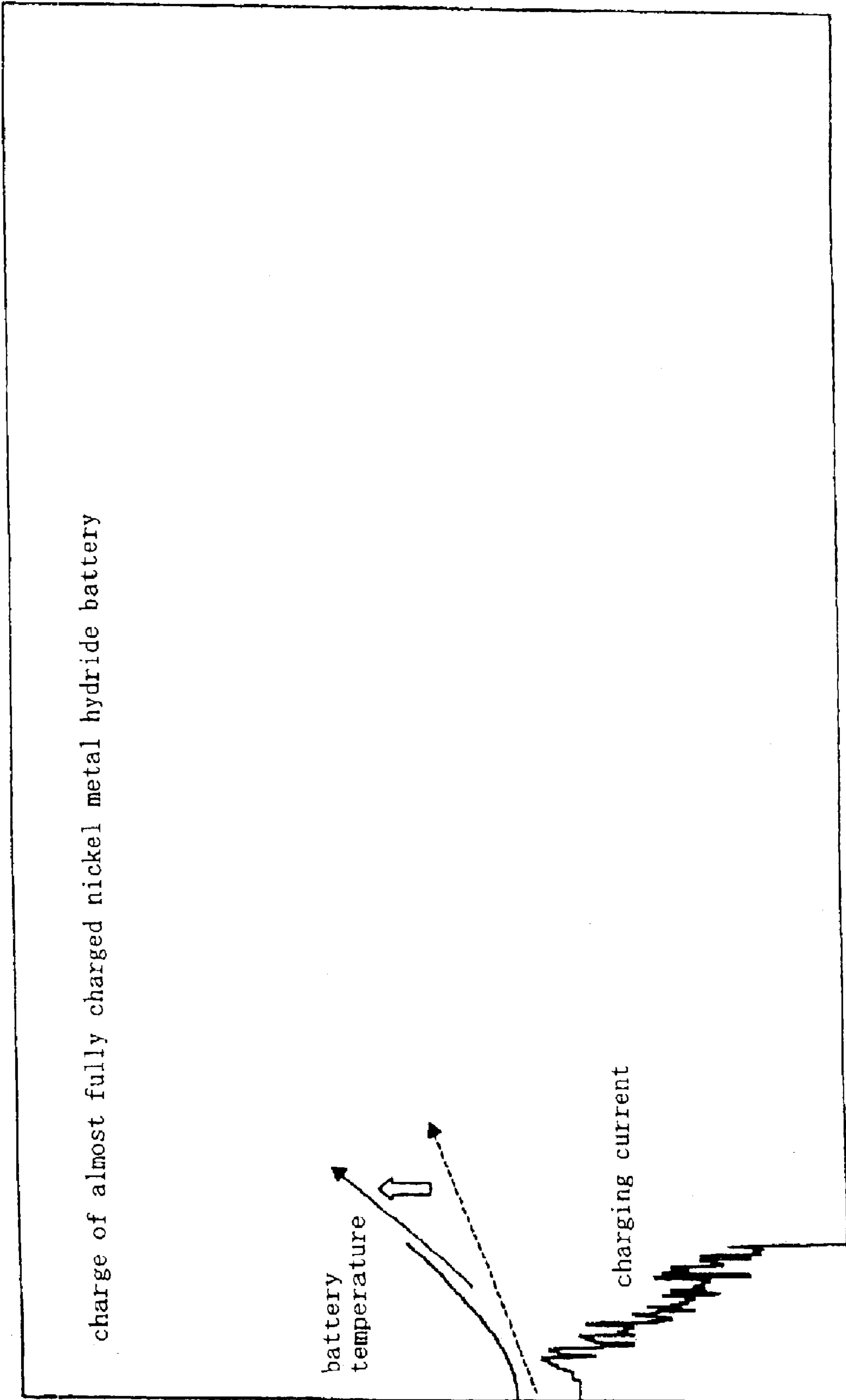


Fig. 8

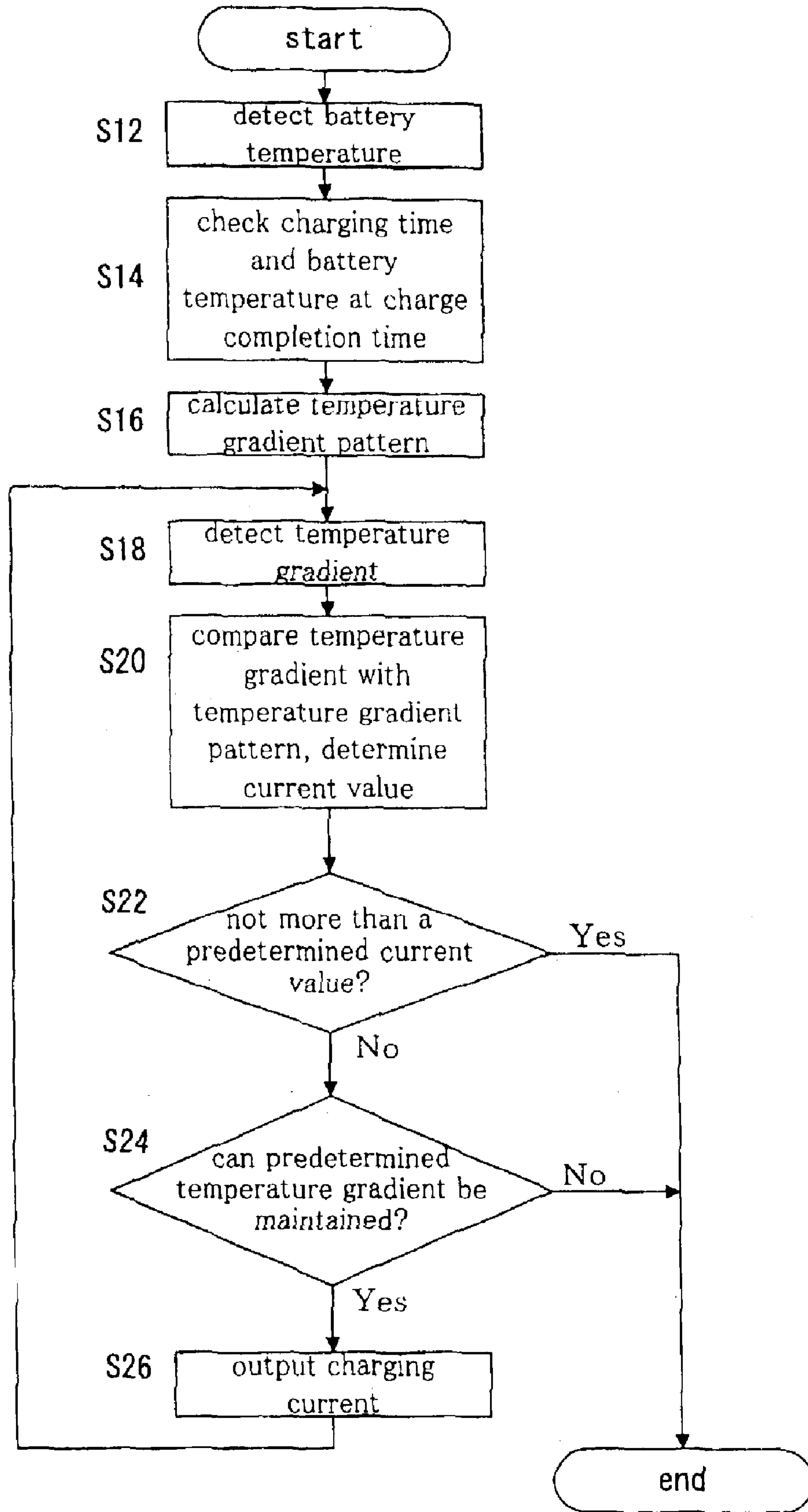


Fig. 9

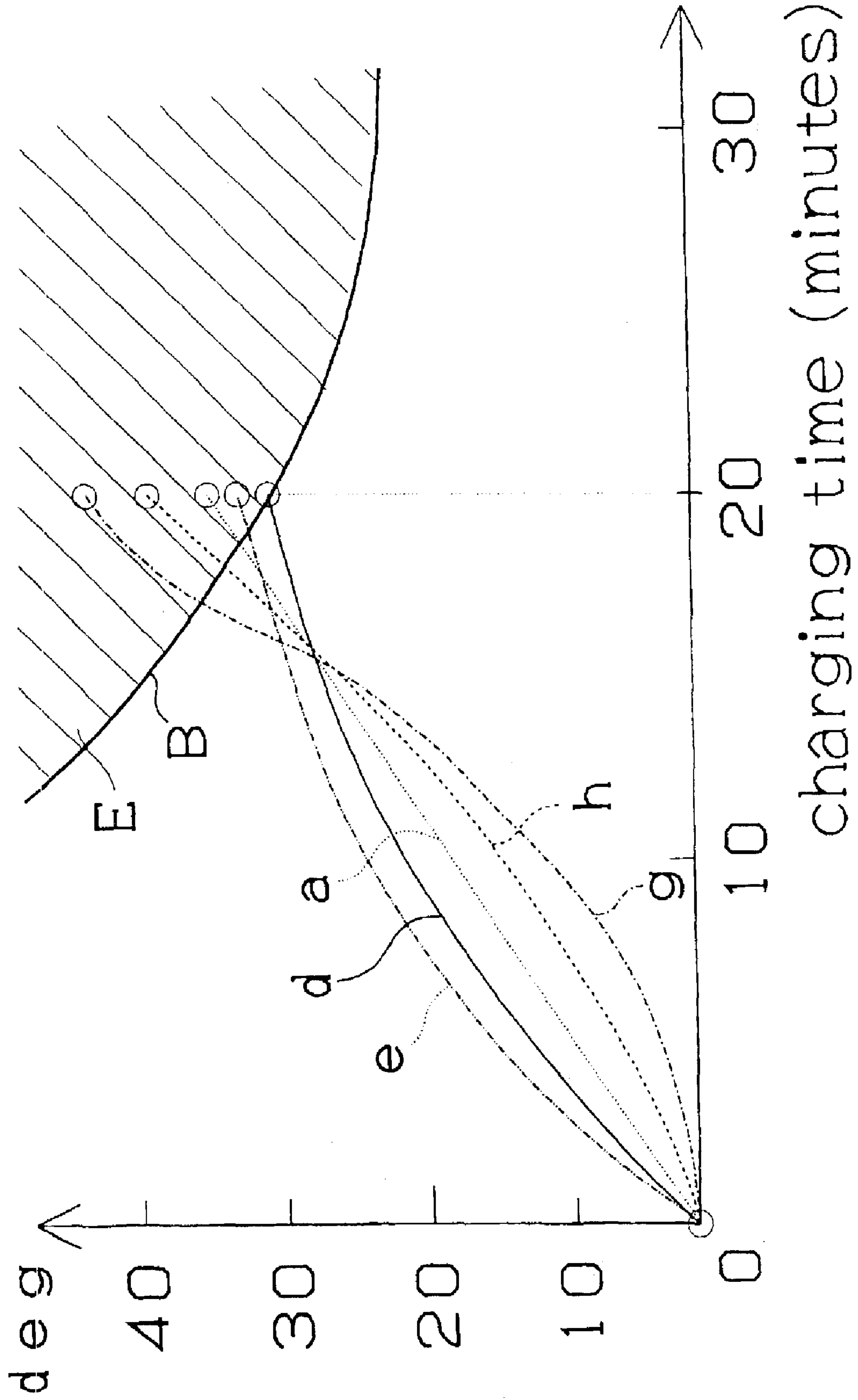


Fig. 10

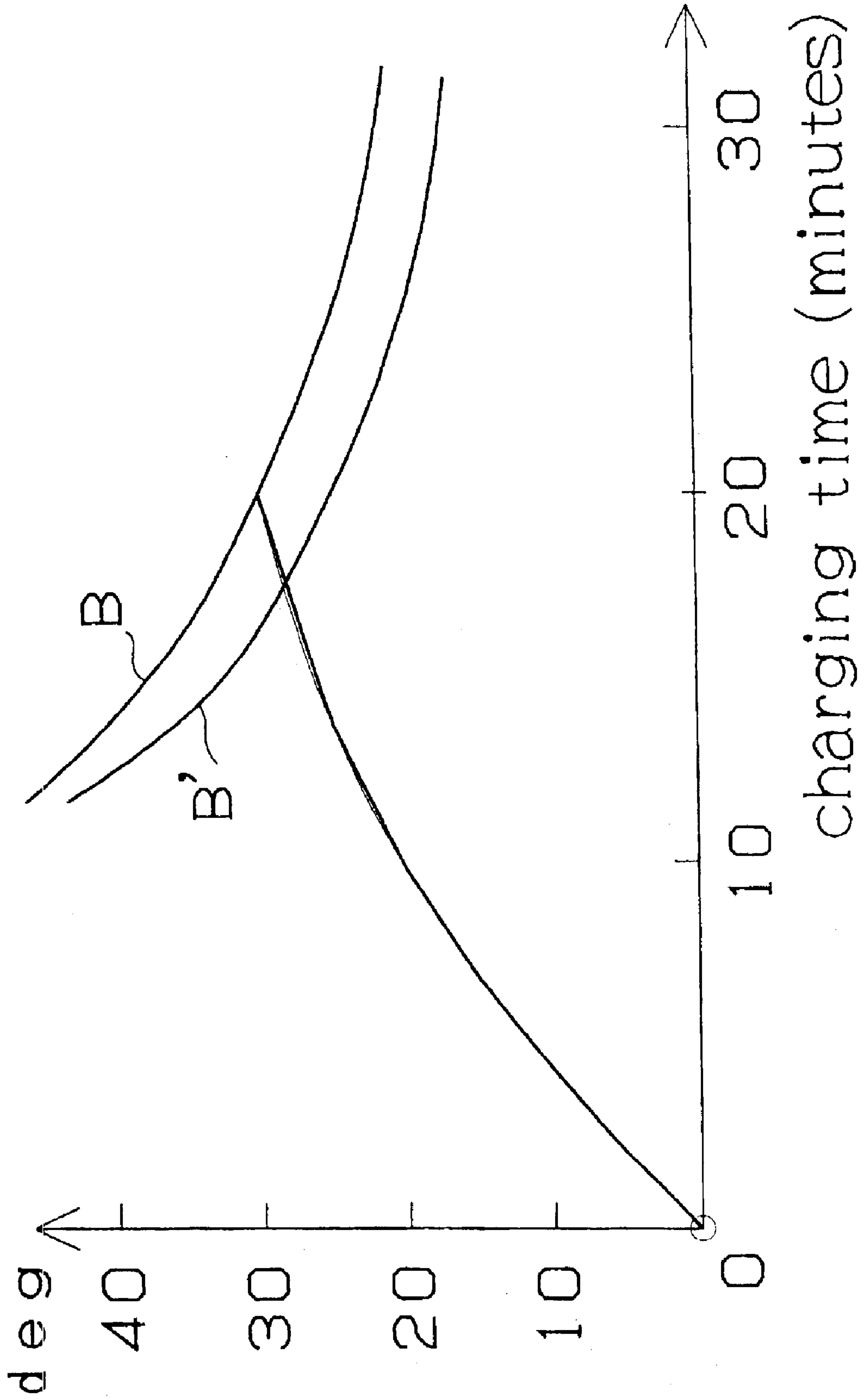


Fig. 11

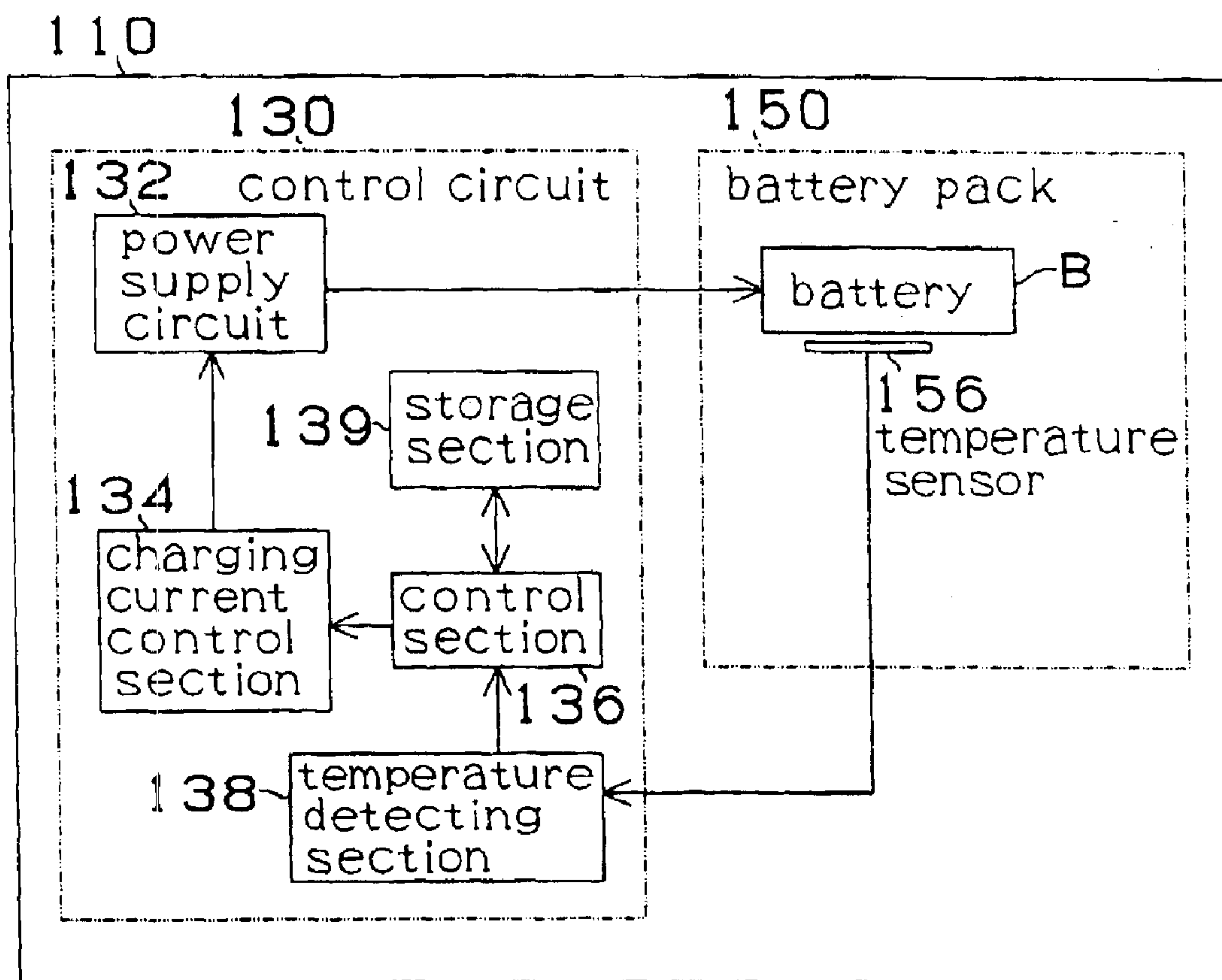


Fig. 12

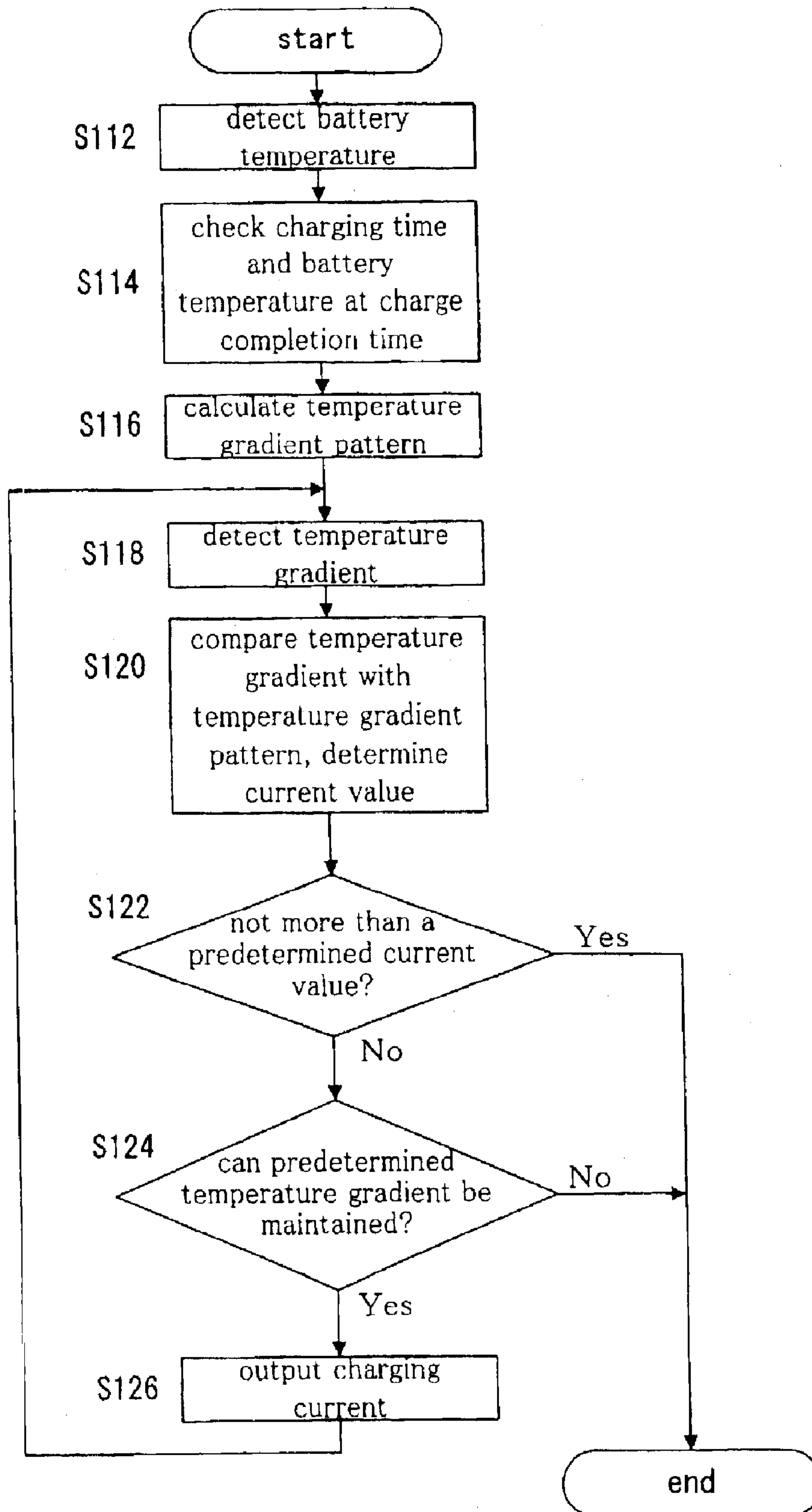


Fig. 13

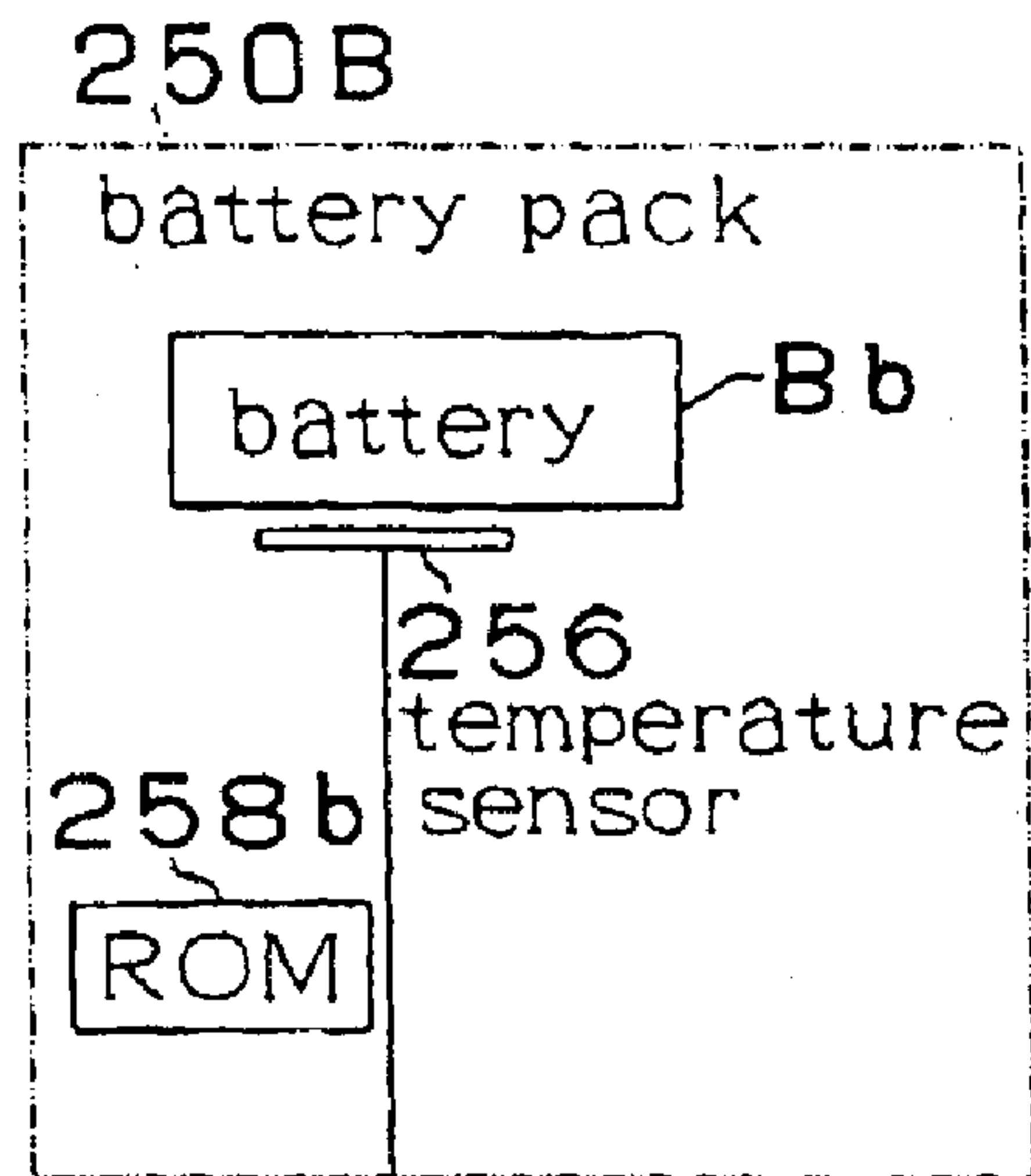
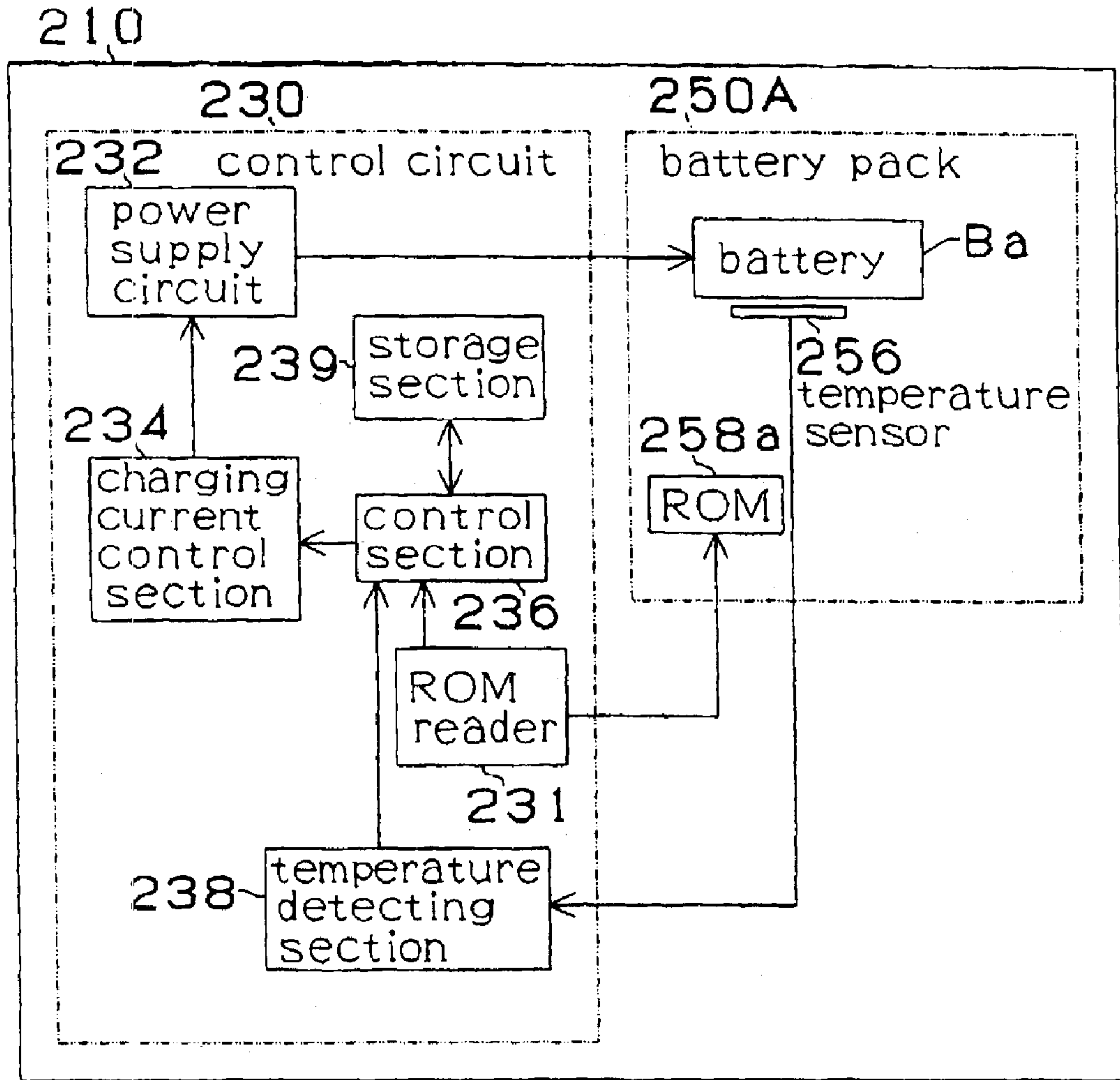


Fig. 14

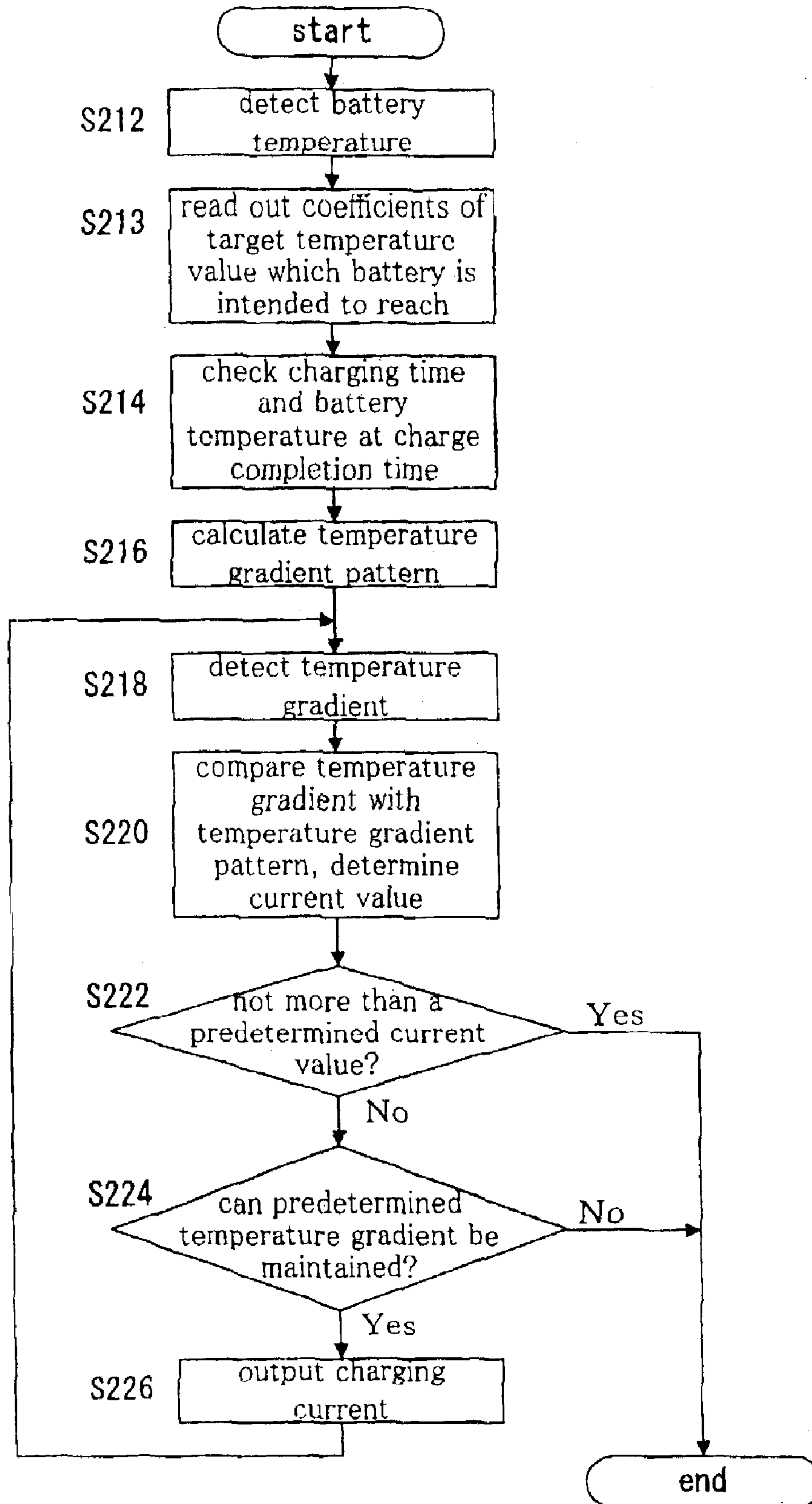
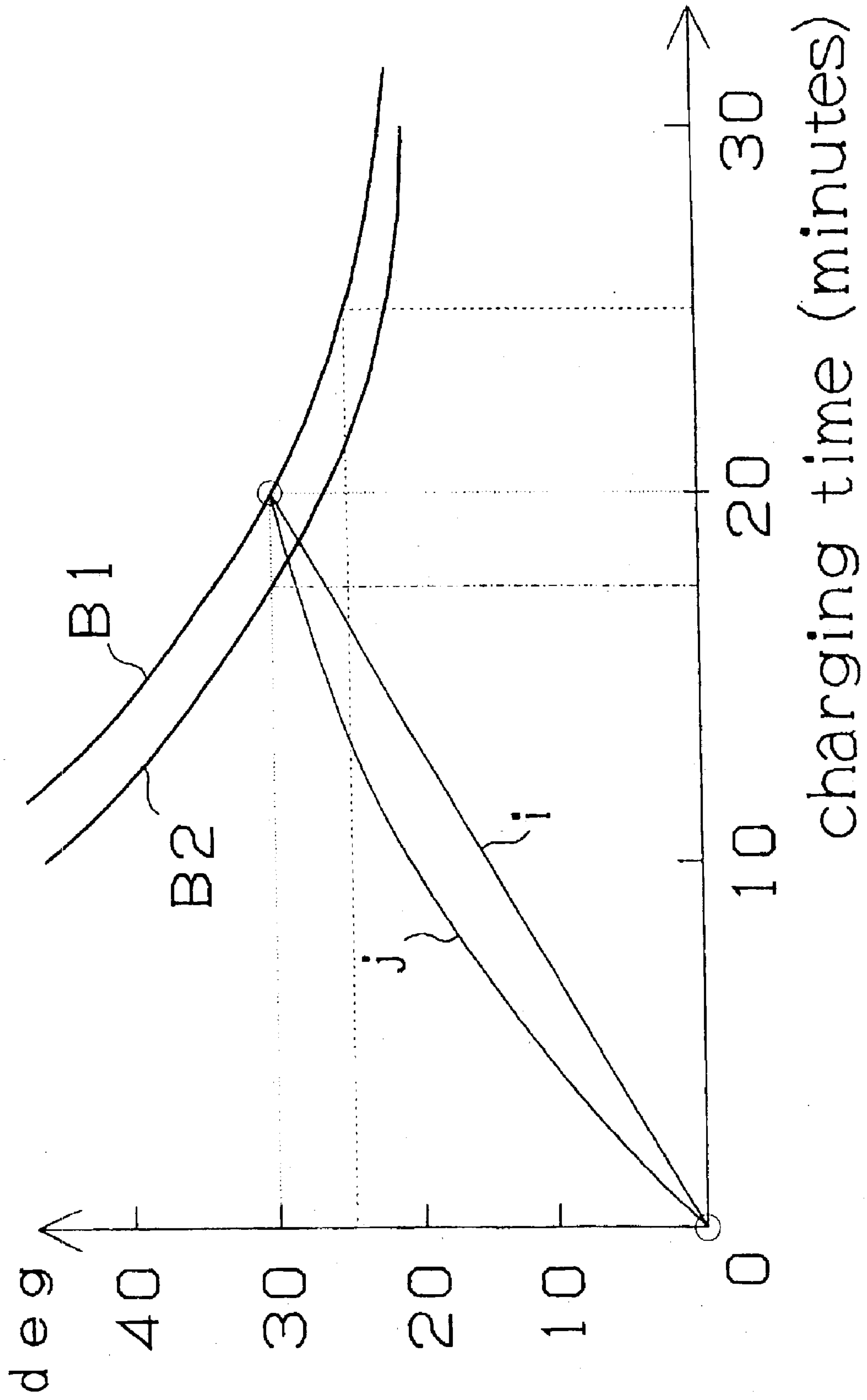


Fig. 15



BATTERY CHARGER AND BATTERY CHARGING METHOD

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This is a reissue of U.S. Pat. No. 6,204,640, issued on Mar. 20, 2001.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a battery charger and a battery charging method for charging a battery and particularly relates to a battery charger and a battery charging method suited for charging a battery, such as a nickel metal hydride battery, which emits high heat while being charged.

2. Discussion of the Prior Art

Presently, a chargeable battery which can be repeatedly used for the power supply of, for example, a power tool is used.

A nickel cadmium battery is popular as a battery for the power tool, and a battery charger for quickly charging the battery by applying high current thereto is used. Specifically, the battery is quickly charged in about 20 minutes and a power tool can be continuously used by switching a battery to that which has been charged.

The *present* inventor [of the present invention studied] *has investigated techniques for improving the performance of a power tool by using a nickel metal hydride battery as a battery therefor. Although [the] nickel metal hydride [battery can increase a] batteries have increased charge storage capacity as compared to a nickel cadmium battery, it generates high heat while being charged. If the temperature of the battery becomes high [by] due to the generated heat, the electrodes and separators of the cells within the battery will deteriorate and battery life [is] will be shortened. Due to this, it [is] has been impossible to quickly charge [the] a nickel metal hydride battery [with] using high current as was previously done for [the] nickel cadmium [battery stated above] batteries.*

SUMMARY OF THE INVENTION

[The] *One object of the present invention [has been made to solve] is to overcome the above-stated problems and [an] another object of this invention is to provide a battery charger and a battery charging method capable of appropriately charging a battery in a short time while [suppressing the temperature rise of] avoiding overheating the battery [which is being suppressed] during charging.*

In [order to accomplish the said object] *one aspect of the present teachings, a battery charger [according to the present invention] is characterized by comprising:*

- a temperature detecting section for detecting a present battery temperature;
- a temperature rise value outputting section for obtaining a temperature rise value from the temperature detected by said temperature detecting section;
- a current value retrieving section for retrieving a current value with which the temperature rise value outputted from said temperature rise value outputting section is constant; and
- a charge control section for charging a battery with the current value retrieved by said current value retrieving section.

In [order to accomplish the said object] *another aspect of the present teachings, a battery charger [according to the present invention] is characterized by comprising:*

- a storage device storing a target temperature value which a battery temperature is intended to reach;
- a temperature detecting section for detecting a present battery temperature;
- a temperature gradient calculating section for calculating a temperature rise gradient from charging time based on a difference between a battery temperature at the beginning of battery charge and said target temperature value held by said storage device;
- a temperature rise value outputting section for obtaining a temperature rise value from the temperature detected by said temperature detecting section;
- a current value retrieving section for retrieving a current value with which the temperature rise value outputted from said temperature rise value outputting section becomes said temperature rise gradient; and
- a charge control section for charging the battery with the current value retrieved by said current value retrieving section.

In [order to accomplish the said object] *another aspect of the present teachings, a battery charger [according to the present invention] is characterized by comprising:*

- a storage device storing a target temperature value which a battery is intended to reach;
- a temperature detecting section for detecting a present battery temperature;
- a temperature rise pattern retrieving section for retrieving a temperature rise pattern for completing battery charge at said target temperature value based on a difference between a battery temperature at the beginning of the battery charge and said target temperature value held by said storage device;
- a temperature rise value outputting section for obtaining a temperature rise value from the temperature detected by said temperature detecting section;
- a current value retrieving section for retrieving a current value with which the temperature rise value outputted from said temperature rise value outputting section becomes said temperature rise pattern; and
- a charge control section for charging the battery with the current value retrieved by said current value retrieving section.

[In accordance with the more preferred teaching of the present invention, said] *A preferred temperature rise pattern [is such that the] includes a temperature [rise value] increase rate that is relatively high in a first half of a battery charge operation and is relatively low in a second half of the battery charge operation.*

[In accordance with the more preferred teaching of the present invention, said] *Another preferred temperature rise pattern is approximated polygonally.*

[In accordance with the more preferred teaching of the present invention, said] *A preferred target temperature value [is a value for completing] completes the battery charge [at the lowest temperature] while minimizing the increase in battery temperature.*

A preferred battery charging method [for making a battery side hold information on] includes storing information concerning a target temperature value[, which a] in the battery [is intended to reach,] corresponding to charging time and charging the battery [by means of] using a battery charger in accordance with the target temperature value, [according to

the present invention] characterized in that [said] *the* battery charger comprises:

- a storage device storing a temperature rise pattern for completing battery charge at the target temperature value read out from the battery side;
- a temperature detecting section for detecting a present battery temperature;
- a temperature rise pattern retrieving section for retrieving a temperature rise pattern from said storage device based on a battery temperature at the beginning of the battery charge and charging time;
- a temperature rise value outputting section for obtaining a temperature rise value from the temperature detected by said temperature detecting section;
- a current value retrieving section for retrieving a current value with which the temperature rise value outputted from said temperature rise value outputting section becomes said temperature rise pattern; and
- a charge control section for charging the battery with the current value retrieved by said current value retrieving section.

In accordance with the more preferred teaching of the present invention, said target temperature value is a value for completing the battery charge at the lowest temperature.

A battery is charged while adjusting [a] *the charging* current [value] so that [a] *the battery* temperature [rise value] *increase rate* may be *substantially* constant. This makes it possible to charge the battery so that [a] *the battery* temperature at the time of the completion of charge [becomes] *will be* a predetermined value. It is, therefore, possible to charge a nickel metal hydride battery or the like [which has large temperature increase] in a short time without [increasing] *overheating* the battery [temperature].

A temperature [rise] *increase* pattern is retrieved [from charging time] based on the difference between [a] *the battery* temperature at the beginning of battery charge and [a] *the target* temperature value which the battery is intended to reach and which is [held by] *stored in* a storage device. The battery is then charged while adjusting [a] *the charging* current [value] so that [a] *the battery* temperature [rise value may become] *increase rate follows* the temperature [rise] *increase* pattern. Due to this, by optimizing the temperature [rise] *increase* pattern, it is possible to charge the battery so that a battery temperature at the time of the completion of charge may [become] *be* a predetermined value. It is, therefore, possible to charge a nickel metal hydride battery or the like [which has a large temperature increase.] in a short time without [increasing] *overheating* the battery [temperature].

[A temperature rise pattern is retrieved from charging time based on the difference between a battery temperature at the beginning of battery charge and a target temperature value which a battery is intended to reach and which is held by a storage device. The battery is then charged while adjusting a current value so that a temperature rise value may become the temperature rise pattern. Due to this, by optimizing the temperature rise pattern, it is possible to charge the battery so that a temperature at the time of the completion of charge may become the target temperature value which the battery is intended to reach (the lowest temperature).]

A temperature rise pattern is set such that the difference between a battery temperature and an ambient temperature is small, a battery is difficult to cool, battery capacity is almost empty, temperature rise during battery is relatively small and a temperature rise value is relatively high in the

first half of the battery charge, and set conversely such that the difference between the battery temperature and the ambient temperature is large, the battery is easily cooled, temperature rise during battery charge is relatively large and the temperature rise value is relatively low in the second half of the battery charge. That is, by setting the temperature rise pattern so as to optimize them altogether in cooperation with one another, it is possible to charge the battery so that the battery temperature at the time of the completion of charge may become the lowest temperature.

Since a temperature rise pattern is approximated polygonally, processing such as arithmetic processing can be easily carried out.

A target temperature value which the temperature is intended to reach is a value for completing battery charge at the lowest temperature and allows charging the battery so that a battery temperature at the completion of charge may become the lowest temperature.

A temperature rise pattern is retrieved from charging time based on the difference between a battery temperature at the beginning of battery charge and a target temperature value which the battery is intended to reach and which is held by the storage device. The battery is then charged while adjusting a current value so that the temperature rise value may become the temperature rise pattern. Due to this, by optimizing the temperature rise pattern, it is possible to charge the battery so that the temperature at the time of the completion of charge may become the target temperature value which the battery is intended to reach (the lowest temperature).

Further, since the battery side holds data on the target temperature value which the battery is intended to reach, it is possible to charge different types of batteries so that temperatures at the time of the completion of charge may become the target temperature values (the lowest temperatures), respectively. In various types of battery chargers, even a battery charger capable of quickly charging a battery in, for example, 15 minutes or that capable of charging a battery in one hour, it is possible to charge the battery so that the battery temperature at the time of the completion of charge may become the target temperature value which the battery is intended to reach (the lowest temperature).

Target temperature value which the battery is intended to reach is a value for completing battery charge at the lowest temperature and allows charging the battery so that the temperature at the time of the completion of charge may become the lowest temperature value.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a battery charger in embodiments according to the present invention.

FIG. 2 is a perspective view of a battery pack in the embodiments according to the present invention.

FIG. 3 is a perspective view of a battery-powered drill [employing] *utilizing* the battery pack shown in FIG. 2.

FIG. 4 is a block diagram showing a control circuit in the battery charger shown in FIG. 1.

FIG. 5 is an explanatory view for the charge principle of a battery charger in the first embodiment according to the present invention.

FIG. 6 is a graph showing the changes of charging current and battery temperature controlled by the battery charger.

FIG. 7 is a graph showing the changes of charging current and battery temperature controlled by the battery charger.

FIG. 8 is a flow chart showing processing in the control section of the battery charger in the first embodiment.

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FIG. 9 is an explanatory view for the charge principle of a battery charger in the second embodiment.

FIG. 10 is an explanatory view for the control principle of the battery charger in the second embodiment.

FIG. 11 is a block diagram showing the control circuit of the battery charger in the second embodiment.

FIG. 12 is a flow chart showing processing in the control section of the battery charger in the second embodiment.

FIG. 13 is a block diagram showing the control circuit of a battery charger in the third embodiment.

FIG. 14 is a flow chart showing processing in the control section of the battery charger in the third embodiment.

FIG. 15 is an explanatory view showing the control principle of a battery charging method in the third embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Battery chargers and battery charging methods according to the embodiments of the present invention will be described hereinafter with reference to the accompanying drawings.

[The embodiments which embody the present invention will now be described with reference to the accompanying drawings.]

FIG. 1 shows a battery charger 10 [in] of the first embodiment of the present invention, FIG. 2 shows a battery pack 50 charged by the battery charger 10 and FIG. 3 shows a battery-powered drill 70 driven by the battery pack 50.

As shown in FIG. 2, the battery pack 50 containing a nickel metal hydride battery cell consists of a generally cylindrical fitted part 52 and a generally prismatic base 55. A key-shaped key part 54 is formed on the side of the fitted part 52 and the first input terminal t1 connected to the positive electrode of the battery, the second input terminal t2a connected to the negative electrode thereof and the third terminal t3 connected to a temperature sensor consisting of a thermistor are arranged on the upper portion of the fitted part 52.

As shown in FIG. 1, the battery charger 10 charging the battery packs 50 is provided with a fitting hole 12 into which the fitted part 52 of the battery pack 50 is fitted. A keyway 14 for introducing the key part 54 of the fitted part 52 is formed on the sidewall of the fitting hole 12. The fitting hole 12 is resin molded integrally with a housing 16 forming the battery charger 10. In this embodiment, the key part 54 is provided at the fitted part 52 of the battery pack 50 and the keyway 14 is provided at the fitting hole 12 of the battery charger 10, thereby preventing the battery pack 50 from being installed in a wrong direction. The first to third output terminals, which are not shown, are provided at the bottom of the fitting hole 12 to contact with the first to third terminals t1, t2a and t3 of the battery pack 50, respectively. An LED lamp 18 is provided on the upper portion of the battery charger 10 to indicate that battery charge is being conducted.

As shown in FIG. 3, the battery-powered drill 70 [is provided with] includes a fitting hole 72 into which the fitted part 52 of the battery pack 50 is fitted, and is [constituted] designed so as to rotate a chuck 76 [by] using a motor, which is not shown, when supplied with power from the first input terminal t1 and the second input terminal t2a of the battery pack 50. When the battery-powered drill 70 is used, a plurality of batteries in the battery pack 50, each of which [are completed with charge] has been completed charged,

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are sequentially used so that the battery-powered drill 70 can continuously operate. To this end, the battery charger [in] 10 of this embodiment is [constituted] designed so as to be capable of quickly charging the battery pack 50 in about 30 minutes.

FIG. 4 shows the configuration of a control circuit 30 in the battery charger 10. The control circuit 30 consists of a temperature detecting section 38 detecting a battery temperature from an output value from a temperature sensor (thermistor) 56 provided at the battery pack 50 side, a storage section 39 storing current value control information to be described later, a control section 36 differentiating the temperature value outputted from the temperature detecting section 38, obtaining a temperature rise value, obtaining a current value with which a battery is chargeable while suppressing the temperature rise value and outputting the current value as a current command value to a charging current control section 34, and the charging current control section 34 controlling a power supply circuit 32 based on the current command value from the control section 36 and adjusting battery charging current.

Next, the operation principle of the battery charger in the first embodiment will be described.

If the charging current [for a] supplied to the battery [increases] is increased, charging time becomes shorter but battery temperature [rise] increase becomes larger. Conversely, if the charging current [decreases] is decreased, charging time becomes longer but battery temperature [rise] increase becomes smaller. A nickel metal hydride battery, in particular, has characteristics that a temperature gradient (temperature [rise value] increase rate) varies greatly with the charging current and the already charged capacity. Due to this, in this embodiment, battery charge is conducted while [changing the] adjusting the charging current [value] so as to [suppress] minimize battery temperature [rise] increase. In other words, [the] conventional battery [charger charges] chargers charge a battery [with] using a fixed current value, whereas the battery charger [in] of this embodiment determines the state of [a] the battery based on [a] the battery temperature [rise value] increase rate and charges the battery while changing the charging current [value] with which the temperature [rise] increase rate of the battery is made fixed, that is, while changing the charging current [value according] in response to the temperature [rise] increase of the battery.

In this embodiment, if battery temperature is high, relatively low charging current is applied to the battery. If the battery temperature is low, relatively high charging current is applied thereto.

The operation principle of the battery charger in the first embodiment will be described in more detail with reference to FIG. 5. In FIG. 5, the vertical axis indicates battery temperature rise values and the horizontal axis indicates charging time. A curve L therein shows temperature rise values at the time of the completion of battery charge corresponding to the charging time while the battery is charged so that the temperature rise value may be constant. The curve L indicates, for instance, that if current is controlled so that the battery temperature which starts at 20° C. may reach 53° C. (a temperature rise value of 33 degrees), charging time is 20 minutes, if current is controlled so that the battery temperature may reach 43° C. (a temperature rise value of 23 degrees), charging time is 30 minutes and that if current is controlled so that the battery temperature may reach 78° C. (a temperature rise value of 58 degrees), charging time is 10 minutes.

That is, it is possible to obtain a temperature rise value (gradient) from the charge completion time and the battery temperature rise value at the time of the completion of battery charge based on the curve L. For example, to complete battery charge in 20 minutes, battery charge may be conducted so as to have a temperature gradient (temperature rise value) indicated by a straight line a which connects 0 deg in FIG. 5 and 33 deg on the curve L. In this case, battery charge is completed almost exactly in 20 minutes when the battery temperature becomes 53° C. (a temperature rise value becomes 33 deg).

The same thing is true for a case where battery charge is completed in 20 minutes at an outside air temperature of 10° C. and a battery temperature of 10° C. Namely, the battery may be charged so as to have a temperature gradient (temperature rise value) indicated by the solid line a which connects 0 deg in FIG. 5 and 33 deg on the curve L. In this case, battery charge is completed at a temperature of 43° C. (a temperature rise value of 33 deg).

Likewise, in case of completing battery charge in 20 minutes at an outside temperature of 30° C. and a battery temperature of 30° C., the battery may be charged so as to have a temperature gradient (temperature rise value) indicated by the solid line a which connects 0 deg in FIG. 5 and 33 deg on the curve L. In this case, battery charge is completed at a temperature of 63° C. (a temperature rise value of 33 deg).

Now, the change of the current value while the above-stated temperature rise value is made constant will be described with reference to FIGS. 6 and 7.

FIG. 6 shows a simulation result when charging a nickel metal hydride battery in 25 minutes so that the battery temperature of 20° C. becomes 50° C. To make a temperature rise value constant, it is necessary to frequently adjust a charging current value. FIG. 6 indicates that the current value is relatively high in the first half of battery charge and gradually lower in the second half of battery charge. Here, the charging current is greatly decreased at a temperature of about 50° C., which indicates that the nickel metal hydride battery is completed with charge. In this embodiment, if this phenomenon is detected, battery charge is completed.

FIG. 7 shows a simulation result for another nickel metal hydride battery. When the nickel metal hydride battery is fully charged, a phenomenon referred to as "overshoot" [when] may occur, in which the battery temperature suddenly [rises] increases due to the past charging record, and not due to the present charging current, may occur to the nickel metal hydride battery. When [the] overshoot occurs, it is not possible to maintain the battery temperature [rise value cannot be made no more than] increase rate at a constant value even if the charging current [value] is [lowered] reduced. In this embodiment, battery charge can be completed even if this phenomenon is detected.

Next, battery charge conducted by the battery charger in the first embodiment will be described with reference to the flow chart of FIG. 8 showing the processing.

First, the control section 36 detects the temperature of the battery pack 50 through the temperature detecting section 38 (in S12). Here, it is assumed that an outside air temperature and a battery temperature is 20° C. Next, charging time and charge completion time are checked (in S14). The battery charger in this embodiment is constituted to switch battery charge between quick charge (20-minute charge) and normal charge (30-minute charge). If battery charge is set at the quick charge, the storage section 39 which holds the values of the curve L described above with reference to FIG. 5 is

retrieved to thereby obtain a battery temperature of 53° C. at the time of charge completion. Thereafter, a temperature gradient is calculated (in S16). Here, the gradient of the straight line a connecting 0 deg and 33 deg on the curve L shown in FIG. 5 is obtained.

The control section 36 differentiates the difference between the temperature value inputted from the previous temperature detecting section and the temperature value inputted this time and obtains a temperature rise value (in S18). The control section 36 then compares this detected temperature rise value with the gradient calculated in the step 16 and thereby determines a current value (in S20). Here, if the temperature rise value is lower than the gradient, the current value is increased from the present value. If lower, the current value is decreased.

Next, it is determined whether the charging current value is [not more] less than a predetermined value (in S22). As described above with reference to FIG. 6, if battery charge is completed and the charging current value [becomes no more] is less than the predetermined value ("Yes" in S22), [charge processing] the charging operation is ended. If the charging current value is not less than the predetermined value ("No" in S22), it is further determined whether a predetermined temperature gradient can be maintained by adjusting the charging current value, i.e., whether overshoot [stated] (described above with reference to FIG. 7) has occurred [occurs] (in S24). If overshoot [occurs] has occurred ("No" in S24), the [processing] charging operation is ended. If overshoot [does] has not [occur] occurred ("Yes" in S24), the processing goes to [a]step 26, whereafter the battery is charged with the charging current value determined in [the] step 20 and the [charge processing] charging operation is continued [further].

The battery charger [in] of the first embodiment advantageously facilitates [charge processing] the charging operation since the temperature [rise value] increase rate is made constant. Furthermore, the battery charger charges the battery while adjusting the charging current value so that the temperature [rise value] increase rate becomes the calculated temperature rise gradient. Thus, it is possible to charge the battery so that the temperature at the time of the completion of charge may become a target temperature value which the battery is intended to reach and to charge a nickel metal hydride battery or the like [which has large temperature increase] in a short time without [increasing] overheating the battery [temperature].

In this embodiment, the curve L shown in FIG. 5 is held by the battery charger. It is also possible to hold only the highest charge temperature (e.g., 30 deg) in a range in which the life of the nickel metal hydride battery is not shortened and charging time (e.g., 25 minutes) corresponding to a temperature rise value of 30 deg, to thereby control battery charge to be completed with the temperature rise value of 30 deg. It is also possible to further simplify the structure of the battery charger, to keep the temperature gradient of the battery constant and to charge the battery with this temperature gradient.

Next, a battery charger in the second embodiment according to the present invention will be described with reference to FIGS. 9 to 12. The battery charger in the first embodiment stated above adjusts a current value so as to make a temperature rise value constant. The battery charger in the second embodiment, by contrast, adjusts a current value so that battery temperature increases along a predetermined pattern.

The principle of this battery charge will be described with reference to FIG. 9. In FIG. 9, the vertical axis indicates

temperature rise values and the horizontal axis indicates charging time. A hatched area E indicates a temperature rise value and charging time at the time of the completion of charge. If, for example, a temperature gradient indicated by symbol a is made constant to complete battery charge in 20 minutes as done by the battery charger in the first embodiment, the temperature of the battery becomes 33 deg at the time of the completion of battery charge. On the other hand, if the battery is charged so that the temperature rise value is along an upward round pattern as indicated by a solid lined in FIG. 9, the battery charge can be completed with a temperature rise value of 30 deg. Also, if the battery is charged so that a temperature rise value is along a more upward round pattern than the solid line d, the battery charge can be completed at a temperature rise value of 32 deg. Conversely, if the battery is charged along a trough pattern as indicated by a broken line h, the battery charge is completed at a temperature rise value of 38 deg. If the battery is charged so that a temperature rise value does not conform with a specific pattern as indicated by a dashed line g, the battery temperature rise value increases nearly 43 deg.

That is to say, the hatched area E indicates temperature rise values and charge time of the completion of battery charge when the battery is charged under various conditions. The border line B of the area E indicates the final temperature rise value when the battery charge is completed at the lowest temperature. If the temperature rise value is made constant in the case of the first embodiment, the broken line a shown in FIG. 9 shows that the temperature rise value is 33 deg. If the temperature rise value is along the slightly upward round temperature rise pattern indicated by the solid line d, the battery can be charged at the lowest temperature rise value (30 deg). The reason the battery can be charged at lower temperature when the temperature rise value is along the upward round pattern, than when the temperature rise value is made constant, is considered as follows. The temperature rise pattern is set such that the difference between the battery temperature and the ambient temperature is small, the battery is difficult to cool, the capacity is nearly empty, temperature rise during battery charge is relatively small and the temperature rise value is relatively high in the first half of the battery charge, and set conversely such that the difference between the battery temperature and the ambient temperature is large, the battery is easily cooled, temperature rise during battery charge is relatively large and the temperature rise value is relatively low in the second half of the battery charge. That is, by setting the temperature rise pattern so as to optimize them altogether in cooperation with one another, it is possible to charge the battery so that the battery temperature at the time of the completion of charge may be the lowest. In this embodiment, the battery charge is conducted while adjusting the current value in accordance with the temperature rise pattern with which battery charge can be completed at the lowest temperature based on the above experiment.

FIG. 10 shows the change of the border line B in accordance with the battery temperature. In FIG. 10, the border line B indicates that outside air temperature (20° C.) is equal to the battery temperature. A border line B' indicates that the battery temperature (20° C.) is higher than the outside air temperature (15° C.). In this case, the border line B' is shifted downward from the border line B by 5° C.

FIG. 11 shows the configuration of a control circuit 130 in a battery charger 110 in the second embodiment. The control circuit 130 is the same as that in the first embodiment stated above with reference to FIG. 4. However, unlike the first embodiment, the storage section 139 of the control

circuit 130 in the second embodiment holds a temperature rise pattern stated above with reference to FIG. 9. This temperature rise pattern which is approximately polygonally in a certain time in which the temperature rises 5 deg, is held by the storage section. For example, in case of the temperature rise pattern indicated by the solid lined stated above with reference to FIG. 9, the battery temperature pattern rises 5 deg in two minutes, 10 deg in four minutes, 15 deg in six minutes, 20 deg in nine minutes, 25 deg in 13 minutes and 30 deg in 20 minutes, that is, the pattern is held in the data format of (2, 4, 6, 9, 13, 20), whereby the capacity of the storage section is intended to be reduced and the arithmetic processing of the control section 136 is intended to be simplified. At the time of temperature control, the charging current is adjusted so as to follow a gradient approximated for every 5 deg as shown in FIG. 10.

In case of charging the battery at a temperature of, for example, 20° C. at an outside air temperature of 15° C., the battery charger 110 calculates a pattern in which a temperature rise value at the time of the completion of charge is decreased by 5° C. is calculated as stated above with reference to FIG. 10 and charges the battery in accordance with this pattern. Conversely, the outside air temperature is 25° C. and the battery temperature is 20° C., the battery charger 110 calculates a pattern in which a temperature rise value at the time of the completion of charge is increased by 5° C.

The specific charge control of the battery charger in the second embodiment will be described with reference to FIG. 12.

First, the control section 136 detects the temperature of the battery pack 150 from the temperature detecting section 138 (in S112). Here, it is assumed that outside air temperature is 20° C. and battery temperature is 25° C. Next, charging time and battery temperature at the time of the completion of charge are checked (in S114). In this case, when charging time is 20 minutes, the final temperature rise value of 35 degrees (30 deg+5 deg) is obtained. Thereafter, a temperature rise pattern is calculated (in S116).

The control section 136 differentiates the difference between the temperature value inputted from the previous temperature detecting section and the temperature value inputted this time and obtains a temperature rise value (in S118). The control section 136 then compares this detected temperature rise value with the temperature rise pattern calculated in the step 116 and thereby determines a current value (in S120). Here, if the temperature rise value is lower than the temperature gradient, the current value is increased from the present value. Conversely, if lower, the current value is decreased.

Next, it is determined whether the *charging* current value is [not more] *less* than a predetermined value (in S122). As in [the case of] the first embodiment, if battery charge is completed and the *charging* current value [becomes not more] *is less* than the predetermined value (“Yes” in S122), [charge processing] *the charging operation* is ended. On the other hand, if the current value is not less than the predetermined value (“No” in S122), it is further determined whether a predetermined temperature gradient can be maintained by adjusting the *charging* current value, i.e., whether overshoot [occurs] *has occurred* (in S124). If overshoot [occurs] *has occurred* (“No” in S124), the [processing] *the charging operation* is ended. If overshoot [does] *has not occur* *occurred* (“Yes” in S124), the processing goes to [a] step 126, whereafter the battery is charged with the *charging* current value determined in [the] step 120 and the charge [processing] *operation* is continued [further].

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The battery charger in the second embodiment charges a battery while adjusting the current value so that the temperature rise value becomes a temperature rise pattern. Due to this, as stated above with reference to FIG. 9, by optimizing the temperature rise pattern, it is possible to charge the battery so that the battery temperature at the time of the completion of charge may become a target temperature value which the battery is intended to reach (the lowest temperature).

The battery charger in this embodiment sets the temperature rise pattern to be round upward, i.e., sets the temperature rise pattern such that the difference between the battery temperature and the ambient temperature is small, the battery is difficult to cool, the capacity is nearly empty, the temperature rise during battery charge is relatively small and the temperature rise value in the first half of the battery charge is relatively high, and set conversely such that the difference between the battery temperature and the ambient temperature is large, the battery is easily cooled, temperature rise during battery charge is relatively large and the temperature rise value in the second half of battery charge is relatively low. That is, by setting the temperature rise pattern so as to optimize them altogether in cooperation with one another, it is possible to charge the battery so that the battery temperature at the time of the completion of charge may be the lowest.

Next, a battery charging method in the third embodiment according to the present invention will be described with reference to FIGS. 13 to 15.

In the second embodiment stated above, the battery charger holds the charging time and final battery temperature rise values shown in FIG. 10. In the third embodiment, by contrast, a battery pack holds border lines each indicating the final temperature when battery charge is completed at the lowest temperature described above with reference to FIG. 9. Namely, the final temperature which the battery reaches when it is completed with charge differs depending on the voltage of the battery pack (the number of battery cells), the type of the battery (nickel metal hydride batteries may have different characteristics), the heat radiation characteristics of the battery pack and the like. Due to this, the battery charger in this embodiment is intended to be capable of charging any battery pack most efficiently by making the battery pack hold the border values (to be referred to as a target temperature values which the battery is intended to reach).

The configuration of a battery charger 210 and battery packs 250A and 250B for the battery charging method in the third embodiment will be described with reference to FIG. 13. The battery pack 250A is provided with a ROM 258a which holds a target temperature value (B1 in FIG. 15) which the battery pack 250A is intended to reach. The battery pack 250B is provided with a ROM 258b which holds a target temperature value (B2 in FIG. 15) which the battery pack 250B is intended to reach. It is noted that the target temperature values B1 and B2 are expressed by a formula of $Y = \beta / (X + \alpha) + \gamma$ and that the values of coefficients α , β and γ are written in the ROM 258a and ROM 258b, respectively.

Meanwhile, a control circuit 230 in the battery charger 210 is provided with a ROM reader 231 for reading out the contents of the above-stated ROM's 258a and 258b. A storage section 239 contains an equation for obtaining a temperature rise pattern. The remaining constituent elements are the same as those in the first embodiment described above with reference to FIG. 4. No description hereto will be, therefore, given herein.

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The specific charge control of the charging method in the third embodiment will be described with reference to FIG. 14.

First, the control section 236 of the battery charger 210 detects the temperature of the battery pack 250A from a temperature detecting section 238 (in S212). Here, it is assumed that the battery temperature is 20° C. Next, the coefficients α , β , and γ for obtaining the target temperature value B1 are read out from the ROM 258a of the battery pack 250A and a curve of the target temperature value B1 shown in FIG. 15 is calculated (in S213). Then, charging time and battery temperature at the time of the completion of battery charge are checked (in S214). Here, the battery charger 210 is constituted to switch battery charge between quick charge and normal charge. In quick charge, a battery temperature rise value of up to 30 deg is allowed. In normal charge, the battery charge is to be completed with a temperature rise of not more than 25 deg. If normal charge is selected, charging time of 25 minutes is confirmed from the temperature rise value of 25 deg at the time of the completion of charge. On the other hand, if quick charge is set, charge time of 20 minutes is confirmed. Thereafter, a temperature gradient pattern is calculated (in S216). If it is confirmed that charge time is 20 minutes in quick charge, an upward round curve (temperature rise pattern) j is calculated based on the equation in the storage section 239 from a segment i connecting 0 deg and 30 deg in FIG. 15. In the third embodiment, the temperature rise pattern is calculated based on the equation. It is also possible to hold a plurality of patterns instead of the equation and to relate the patterns to thereby obtain a pattern.

The control section 236 obtains a temperature rise value from the difference between the temperature value inputted from the previous temperature detecting section and the temperature value inputted this time (in S218), this detected temperature rise value is compared with the gradient calculated in the step 216 and thereby a current value is determined (in S220). Here, if the temperature rise value is lower than the temperature rise pattern, the current value is increased from the present value. If lower, the current value is decreased.

Next, it is determined whether the *charging* current value is [not more] *less* than a predetermined value (in S222). As in [the case of] the first embodiment, if battery charge is completed and the *charging* current value [becomes no more] *is less* than the predetermined value ("Yes" in S222), [charge processing] *the charging operation* is ended. On the other hand, if the *charging* current is [no less] *more* than the predetermined value ("No" in S222), it is further determined whether the temperature gradient can be maintained by adjusting the *charging* current value, i.e., whether overshoot [occurs] *has occurred* (in S224). If overshoot [occurs] *has occurred* ("No" in S224), [processing] *the charging operation* is ended. If overshoot [does] *has not [occur] occurred* ("Yes" in S224), *the* processing goes to [a] step 226, whereby the battery is charged with the *charging* current value determined in [the] step 220 and *the* charge [processing] *operation* is continued [further].

In the battery charging method in the third embodiment, the battery packs 250A and 250B hold the target temperature values B1 and B2, respectively. Due to this, it is possible to complete charging the battery pack 250A in the shortest time of 20 minutes and charging the battery pack 250B having the target temperature value B2 in the shortest time of 17 minutes (see FIG. 15). Further, in various types of battery chargers, even a battery charger capable of quickly charging a battery in, for example, 20 minutes or that capable of

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charging a battery in one hour, it is possible to charge the battery so that the battery temperature at the time of the completion of charge may become the target temperature value which the battery is intended to reach (the lowest temperature).

Furthermore, in the battery charging method in the third embodiment, battery charge is conducted based on the data held by the battery packs. Due to this, it is possible to easily change the usage of the battery packs or to newly design battery packs and to allow even a battery charger of an old type to conduct optimum charge control based on the newest data.

Although the invention has been disclosed in the context of a certain preferred embodiments, it will be understood that the present invention extends beyond the specifically disclosed embodiments to other alternative embodiments of the invention. Thus, it is intended that the scope of the invention should not be limited by the disclosed embodiments but should be determined by reference to the claims that follow.

What is claimed is:

1. A battery charger characterized by comprising:

a temperature detecting section for detecting a present battery temperature;

a temperature rise value outputting section for obtaining a temperature rise value from the temperature detected by said temperature detecting section;

a current value retrieving section for retrieving a current value with which the temperature rise value outputted from said temperature rise value outputting section is constant; and

a charge control section for charging a battery with the current value retrieved by said current value retrieving section.

2. A battery charger characterized by comprising:

a storage device storing a target temperature value which a battery temperature is intended to reach;

a temperature detecting section for detecting a present battery temperature;

a temperature gradient calculating section for calculating a temperature rise gradient from charging time based on a difference between a battery temperature at the beginning of battery charge and said target temperature value held by said storage device;

a temperature rise value outputting section for obtaining a temperature rise value from the temperature detected by said temperature detecting section;

a current value retrieving section for retrieving a current value with which the temperature rise value outputted from said temperature rise value outputting section becomes said temperature rise gradient; and

a charge control section for charging the battery with the current value retrieved by said current value retrieving section.

3. A battery charger characterized by comprising:

a storage device storing a target temperature value which a battery is intended to reach;

a temperature detecting section for detecting a present battery temperature;

a temperature rise pattern retrieving section for retrieving a temperature rise pattern for completing battery charge at said target temperature value based on a difference between a battery temperature at the beginning of the battery charge and said target temperature value held by said storage device;

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a temperature rise value outputting section for obtaining a temperature rise value from the temperature detected by said temperature detecting section;

a current value retrieving section for retrieving a current value with which the temperature rise value outputted from said temperature rise value outputting section becomes said temperature rise pattern; and

a charge control section for charging the battery with the current value retrieved by said current value retrieving section.

4. A battery charger according to claim 3, characterized in that said temperature rise pattern is such that the temperature rise value is relatively high in a first half of battery charge and is relatively low in a second half of battery charge.

5. A battery charger according to claim 3, characterized in that said temperature rise pattern is approximated polygonally.

6. A battery charger according to claim 4, characterized in that said temperature rise pattern is approximated polygonally.

7. A battery charger according to claim 3, characterized in that said target temperature value is a value for comprising the battery charge at the lowest temperature.

8. A battery charger according to claims 4, characterized in that said target temperature value is a value for completing the battery charge at the lowest temperature.

9. A battery charger according to claim 5, characterized in that said target temperature value is a value for completing the battery charge at the lowest temperature.

10. A battery charging method for making a battery side hold information on a target temperature value, which a battery is intended to reach, corresponding to charging time and charging the battery by means of a battery charger in accordance with the target temperature value, characterized in that said battery charger comprises:

a storage device storing a temperature rise pattern for completing battery charge at the target temperature value read out from the battery side;

a temperature detecting section for detecting a present battery temperature;

a temperature rise pattern retrieving section for retrieving a temperature rise pattern from said storage device based on a battery temperature at the beginning of the battery charge and charging time;

a temperature rise value outputting section for obtaining a temperature rise value from the temperature detected by said temperature detecting section;

a current value retrieving section for retrieving a current value with which the temperature rise value outputted from said temperature rise value outputting section becomes said temperature rise pattern; and

a charge control section for charging the battery with the current value retrieved by said current value retrieving section.

11. A battery charging method according to claim 7, characterized in that said target temperature value is a value for completing the battery charge at the lowest temperature.

12. An apparatus for charging a battery comprising:

a controller coupled to a temperature sensing terminal, a charging terminal and a power supply, wherein the controller adjusts the amount of current supplied to the charging terminal by the power supply in order to maintain an actual rate of battery temperature increase approximately equal to a predetermined pattern of battery temperature increase.

13. An apparatus as in claim 12, wherein the controller comprises instructions for stopping the supply of current to

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the battery if the current being supplied to the battery falls below a predetermined current value.

14. An apparatus in claim 12, wherein the controller stores a curve of final battery temperatures versus charging times and generates the predetermined pattern of battery temperature increase based at least in part upon an initial battery temperature and the curve of final battery temperatures.

15. An apparatus for supplying current to a rechargeable battery comprising:

a first terminal arranged and constructed to connect to a battery temperature sensor disposed proximally to the rechargeable battery,

a power supply,

a second terminal coupled to the power supply and adapted to supply current to the rechargeable battery, and

a controller coupled to the first terminal and the power supply, wherein the controller adjusts the amount of current supplied to the second terminal by the power supply in order to maintain an actual rate of battery temperature increase approximately equal to a predetermined rate of battery temperature increase.

16. An apparatus as in claim 15, wherein the controller stops the supply of current to the battery when the current being supplied to the battery is less than a predetermined current value.

17. An apparatus as in claim 15, wherein the controller is further arranged and constructed to:

(i) reduce the amount of current supplied to the rechargeable battery, if the actual rate of battery temperature increase is greater than the predetermined rate of battery temperature increase, and

(ii) increase the amount of current supplied to the rechargeable battery, if the actual rate of battery temperature increase is less than the predetermined rate of battery temperature increase.

18. An apparatus as in claim 17, wherein the predetermined rate of battery temperature increase is a constant rate.

19. An apparatus as in claim 17, wherein the predetermined rate of battery temperature increase is a rate that varies over time.

20. An apparatus as in claim 19, wherein the predetermined rate of battery temperature increase is greater at the beginning of a charging cycle than at the end of the charging cycle.

21. An apparatus as in claim 15, further comprising a memory storing an equation for calculating the predetermined rate of battery temperature increase based at least in part upon an initial battery temperature detected before the charging operation has begun.

22. An apparatus as in claim 15, wherein the controller is further arranged and constructed to stop current to the battery in the event of an overshoot condition.

23. An apparatus as in claim 22, wherein the controller is further arranged and constructed to stop current to the battery when the current being supplied to the battery falls below a predetermined current value.

24. An apparatus as in claim 15, wherein the controller stores a curve of final battery temperatures versus charging times and generates the predetermined pattern of battery temperature increase based at least in part upon an initial battery temperature and the curve of final battery temperatures, wherein the controller is arranged and constructed to stop the supply of current to the battery (1) when

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the actual current supplied to the battery is less than a predetermined current value and (2) in the event of an overshoot condition.

25. An apparatus as in claim 24, wherein the controller is further arranged and constructed to:

(i) reduce the amount of current supplied to the rechargeable battery, if the actual rate of battery temperature increase is greater than the predetermined rate of battery temperature increase, and

(ii) increase the amount of current supplied to the rechargeable battery, if the actual rate of battery temperature increase is less than the predetermined rate of battery temperature increase.

26. An apparatus as in claim 25, wherein the predetermined rate of battery temperature increase is a constant rate.

27. An apparatus as in claim 25, wherein the predetermined rate of battery temperature increase is a rate that varies over time.

28. An apparatus as in claim 27, wherein the predetermined rate of battery temperature increase is greater at the beginning of a charging cycle than at the end of the charging cycle.

29. A method for charging a battery comprising:

detecting an initial battery temperature,

generating a predetermined pattern of battery temperature increase rate based at least in part upon the initial battery temperature,

supplying charging current to the battery,

determining an actual battery temperature increase rate while charging the battery, and

adjusting the amount of current supplied to the battery in order to substantially equalize the actual battery temperature increase rate with the predetermined battery temperature increase rate.

30. A method as in claim 29, wherein the current adjusting step comprises:

(i) reducing the amount of charging current supplied to the battery, if the actual battery temperature increase rate is greater than the predetermined battery temperature increase rate and

(ii) increasing the amount of charging current supplied to the battery, if the actual battery temperature increase rate is less than the predetermined battery temperature increase rate.

31. A method as in claim 30, further comprising:

stopping the supply of charging current to the battery when the amount of charging current being supplied to the battery falls below a predetermined current value.

32. A method as in claim 31, further comprising:

stopping the supply of charging current to the battery when an overshoot condition is detected.

33. A method as in claim 29, further comprising:

stopping the supply of charging current to the battery when the amount of current being supplied to the battery falls below a predetermined current value.

34. A method as in claim 29, further comprising:

stopping the supply of charging current to the battery when an overshoot condition is detected.

35. An apparatus for charging a battery, comprising:

means for sensing a battery temperature of the battery,

means for predetermining a pattern of battery temperature increase rate during battery charging based at least in part upon an initial battery temperature, and

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means for supplying varying charging currents to the battery so that the battery temperature increases during charging substantially according to the predetermined pattern of battery temperature increase rate.

36. An apparatus as in claim 35, wherein the means for supplying varying charging currents to the battery comprises:

(i) means for reducing the amount of charging current supplied to the battery, if the actual battery temperature increase rate is greater than the predetermined battery temperature increase rate and

(ii) means for increasing the amount of charging current supplied to the battery, if the actual battery temperature increase rate is less than the predetermined battery temperature increase rate.

37. An apparatus as in claim 36, further comprising:

means for stopping the supply of charging current to the battery when the amount of charging current being supplied to the battery falls below a predetermined current value.

38. An apparatus as in claim 37, further comprising:

means for stopping the supply of charging current to the battery when an overshoot condition is detected.

39. An apparatus as in claim 35, further comprising:

means for stopping the supply of charging current to the battery when the amount of charging current being supplied to the battery falls below a predetermined current value.

40. An apparatus as in claim 35, further comprising:

means for stopping the supply of charging current to the battery when an overshoot condition is detected.

41. A method for charging a battery, comprising:

selecting a predetermined pattern of battery temperature increase rate, and

supplying varying charging currents to the battery so that the battery temperature increases during charging substantially according to the predetermined pattern of battery temperature increase rate.

42. A method as in claim 41, wherein the predetermined battery temperature increase rate is selected at least in part based upon an initial battery temperature.

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43. A method as in claim 41, wherein the step of supplying varying charging currents to the battery comprises:

(i) reducing the amount of charging current supplied to the battery, if the actual battery temperature increase rate is greater than the predetermined pattern of battery temperature increase rate and

(ii) increasing the amount of charging current supplied to the battery, if the actual battery temperature increase rate is less than the predetermined pattern of battery temperature increase rate.

44. A method as in claim 43, further comprising:

stopping the supply of charging current to the battery when the amount of charging current being supplied to the battery falls below a predetermined current value.

45. A method as in claim 44, further comprising:

stopping the supply of charging current to the battery when an overshoot condition is detected.

46. A method as in claim 41, further comprising:

stopping the supply of charging current to the battery when the amount of current being supplied to the battery falls below a predetermined current value and

stopping the supply of charging current to the battery when an overshoot condition is detected.

47. A method for charging a battery comprising:

generating a predetermined pattern of battery temperature increase during a charging operation,

supplying charging current to the battery and monitoring an actual battery temperature increase rate while charging the battery,

reducing the amount of charging current supplied to the battery, if the actual battery temperature increase rate is greater than the predetermined pattern of battery temperature increase rate and

increasing the amount of charging current supplied to the battery, if the actual battery temperature increase rate is less than the predetermined pattern of battery temperature increase rate.

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