METHOD AND INSTALLATION FOR FAST CHARGING OF ACCUMULATORS OR BATTERIES

Method for charging an accumulator or battery, wherein a relatively high charge current is supplied to the accumulator and the charge current, or a voltage representative thereof, or the accumulator voltage is measured in order to follow the change in the charge current, or a voltage representative thereof, or the accumulator voltage during charging, and the point in time at which the accumulator is fully or essentially fully charged is determined, at which point in time charging is terminated or at least the charge current is appreciably reduced, and to which end, in order to determine the point in time during charging at which fast charging is terminated, the charge current, or a voltage representative thereof, or the accumulator voltage is measured successively at various points in time, and the data from, considered over time, the last N measurements, where N is at least 3, are used to calculate the increase or decrease in the charge current, or a voltage representative thereof, or the accumulator voltage R over time.

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Method and installation for fast charging of accumulators or batteries

The invention relates to the fast charging of accumulators or batteries. In particular, the invention relates to charging batteries or accumulators using a charge current which is as high as possible, which batteries or accumulators do not need to have any particular construction with regard to charging with high charge currents. More particularly, the invention relates to the determination of the degree of charging of the accumulators or batteries during charging with high charge current, in order, on the basis of said determination, to terminate fast charging in order, for example, to change over to so-called trickle charging. In this context the term accumulator or battery is used to define any type of element which is capable of storing an electrical charge by electrochemical means, such as, for example, Nicd or NiMH batteries, but also the large accumulators for electrically powered traction which are customarily used in transport. In the text which follows the term accumulator is used, but it will be apparent that this is also used in the sense of battery.

When recharging an accumulator there is a risk of damage as a consequence of, for example, heat generation or pressure build-up in the interior of the accumulator. Such risks increase the greater the charge current. It can be particularly harmful to continue using a high charge current to charge an accumulator which, in the interim, has become fully or virtually fully charged. On the one hand, it has been attempted to solve this problem using special accumulators which are less vulnerable to overcharging with a high charge current, but, however, are particularly expensive. On the other hand, lower permissible charge currents are prescribed for the more customary less expensive accumulators, as a result of which the charging time, however, can be restricted to no less than, for example, one hour. In the meantime, various charge algorithms have been developed in order to restrict as far as possible any possible risk of damage to the accumulator when using a charge current which is as high as possible, that is to say a charging time which is as short as possible. The article "Fast-charge batteries, team with control circuits to serve portable equipment", EDN, 7 December 1989, pages 180-186 provides a review in this context. In practice, it is mainly the so-called AU method which is used. To this end, the change in voltage of the accumulator is monitored during
charging. As charging proceeds, the voltage will gradually increase, in order to reach a maximum when the accumulator is fully charged, after which, if charging is continued, the voltage falls. In DE-A 3 334 851 a method and an installation are described with which the point in time of termination of fast charging with a high charge current is determined on the basis of the change in voltage, by briefly interrupting the charge current at various successive points in time, this being known as pulse charging, in order to measure the accumulator voltage at that point in time, in order then to compare the two measurements and to switch off the high charge current as soon as either the last-measured accumulator voltage is lower than that first measured, or the difference between the two measured accumulator voltages is less than a predetermined voltage difference threshold. European Patent Application 0 522 691 also describes a procedure based on the ΔU method, and in the preamble to the description (in particular in columns 1 to 4) gives a more detailed explanation of the problems which must be taken into account when charging electrochemical accumulators.

Consequently, there has already long been a desire for a reliable method for charging an accumulator so as to charge the accumulator fully in the shortest possible time whilst preserving as long as possible a service life, that is to say the number of times that the accumulator can be recharged in practice, with exclusion of the risk of damage to the accumulator as a consequence of overcharging. However, to date it has proved not to be adequately possible to meet the desire referred to above.

The present invention proposes a method and an installation with which, in comparison to the prior art, it is possible to come appreciably closer to meeting the desire to charge any type of accumulator, in particular an accumulator of the standard type, in as short a time as possible, that is to say using as high a charge current as possible, having regard to the usual service life and with exclusion of the risk of damage.

In accordance with Claim 1, appended to this description, the invention proposes, to this end, using the so-called shifting segment method, to determine on the basis of the change in the charge current, or a voltage representative thereof, or the accumulator voltage, the point in time at which the accumulator is fully or essentially fully charged, in order at that point in time to remove the applied relatively
high constant or pulsed charge current and, for example, to change over to trickle charging or to continue charging at an appreciably lower charge current. In this context the term "voltage representative" of the charge current indicates, for example, that the magnitude of the charge current is determined by measuring the voltage over a shunt resistor, placed in series with the accumulator. However, this is not the only way in which the charge current can be determined. Contact-free current measurement on the basis of the so-called Hall effect is, for example, also possible.

Surprisingly, it has been found that in accordance with the present invention the point in time at which the accumulator is fully charged can be determined particularly accurately and reliably. In particular, the reliability of the method according to the invention is important here, since an accumulator will, on average, be recharged many tens to hundreds or more than a thousand times and, thus, for every accumulator the relatively high charge current will have to be removed just as often at the correct point in time. As a result of the accuracy and the reliability, it is now possible to maintain the relatively high constant or pulsed charge current as long as possible, so that subsequent top-up charging using a lower charge current in order to obtain the maximum degree of charging is not necessary or is necessary for only a very short time, which results in yet a further shortening of the charging procedure.

According to the present invention, a constant or pulsed fast-charge current which is at least 3 C is used. By this means an accumulator of the so-called penlite type can be charged within approximately ten to twenty minutes. The said charge current can also be used for accumulators of the so-called alkaline type, such as NiCd batteries, which are guaranteed by the manufacturer only for appreciably lower charge currents, as a result of which the charging time is at least two to three hours and usually about fourteen hours.

The method according to the present invention is suitable for charging both with a pulsed charge current and with a constant charge current. Charging with a pulsed charge current is known per se. In this context, the accumulator voltage is measured at the point in time when there is no charge current pulse. Various trials have been carried out in an attempt to optimise the service life of an accumulator by choosing a suitable method of charging with a pulsed charge current. In this

However, it has been found, surprisingly, that when charging is carried out using an essentially constant charge current the cycle service life of the accumulator, that is to say the number of times that the accumulator can reasonably be charged, is (appreciably) increased in comparison with that when a pulsed charge current is used for charging. It is presumed that this is due to the combination of a constant charge current and the specific procedure for determining the point in time at which full charging of the accumulator is obtained, by means of the shifting segment method in accordance with the invention.

European Patent Application 0 522 691 suggests charging with a constant charge current, but not with a particularly high charge current, and does not indicate the extent to which charging using the proposed procedure leads to a significant shortening of the charging time together with retention of, or improvement in, the cycle service life.

Furthermore, according to the invention it is possible, in a preferred embodiment, to monitor the change in temperature of the accumulator as well as the change in the charge current or the accumulator voltage, for example in order to prevent damage to the accumulator by circumstances which cannot be traced by means of the change in the charge current or the accumulator voltage. The combined use of the change in the accumulator voltage and the accumulator temperature in a switch-off criterion is known per se from, for example, "Ultra-rapid NiCd charger", ELECTRONICS WORLD + WIRELESS WORLD, June 1990, pages 532-534.

Furthermore, the accumulator can be discharged in the conventional manner, prior to charging in accordance with the invention, if said accumulator has a residual charge which is higher than a predetermined permitted residual charge. The occurrence of the so-called memory effect can be prevented by this means.

The single figure shows a diagrammatic representation of an ultra-rapid charger 1 for simultaneous charging of N cells. A charge and discharge circuit 2, 3, N is shown for each accumulator 5. Said circuits 2, 3, N are connected to the various inputs and outputs of a control
unit 4. A diode 6, a resistor 7, a temperature sensor 8, an A/D
converter 9, a switch 10, which is actuated by the control unit 4, and a
power supply 11 providing constant charge current are incorporated in
every circuit. The continuous lines show the position of the switch 10
during discharging; the broken line shows the position of the switch 10
during charging. The battery 5 is incorporated in an easily removable
manner in the circuit 2, 3, N in a manner known per se. It will be clear
to those skilled in the art how the control unit 4 must be programmed
such that the cell voltage of the accumulator 5 can be measured at
successive points in time by means of the A/D converter 9, in order to
determine the point in time for switching off the high charge current on
the basis of the following equation:

\[ R = \sum_{m=1}^{N} mV_m - \frac{1}{N} \sum_{m=1}^{N} \sum_{n=1}^{m} V_n \]

where \( V_m \) is the measured cell voltage for an N-point segment, and
where switching off takes place as soon as \( R \) falls below a predetermined
threshold value. With this arrangement, switching can be carried out in
such a way that after the high charge current has been switched off, the
power supply 11 continues to supply an appreciably lower charge current
of, for example, 0.1 C, or changes over to so-called trickle charging.
Furthermore, it will be clear to those skilled in the art how the ultra-
rapid charger 1 can be adapted for charging using a constant voltage. By
charging using a constant voltage (so-called CV charging), the charge
current, for a given charge voltage, is determined by the accumulator.
Consequently, the charge current is equal to the maximum permissible
charge current without overcharging occurring. During charging of the
accumulator using constant voltage, a descending curve will be measured
for the charge current. However, the fall in the charge current will
change to a rise as soon as the accumulator is fully charged. In
accordance with the present invention, the transition between the
descending and ascending parts of the curve for the charge current when
charging using constant voltage is now determined by the shifting
segment method, in order thus to determine the point in time at which
fast charging is terminated. When charging using constant voltage, it
can optionally be elected to restrict the charge current to a possible
maximum. By this means, in particular, (too) high an initial charge
current is prevented, whilst limiting the charge current to a maximum
has no influence on the customary descending curve of the charge current as a function of time, with, finally, a transition to an ascending curve for the charge current.

The invention is explained in more detail below with the aid of six examples.

**Example 1**
A nickel-cadmium accumulator, of AA size with a capacity of 600 mAh and a usual fast-charging time of 4 hours or more, was charged using a constant charge current of 5 C, corresponding to a charge current of 3.0 A. The charging time was 12 minutes. The charge capacity was 600 mAh, whilst the discharge capacity, determined on discharging at 2 C, which corresponds to 1.2 A, was 530 mAh. This gave a charge efficiency, that is to say the ratio of the discharge capacity to the charge capacity, of 88 %. During charging a maximum temperature of 31 °C was reached, which was measured on the outer wall of the nickel-cadmium accumulator. Consequently, the temperature safety cut-out, which was set for 40 °C, was not triggered.

**Example 2**
A nickel-cadmium accumulator, of AA size with a capacity of 600 mAh and a usual fast-charging time of 4 hours or more, was subjected to a cycle service life test in which, for every cycle, charging was carried out at 4 C, corresponding to a constant charge current of 2.4 A, and discharging was carried out at 2 C, corresponding to a discharge current of 1.2 A. This test showed that after 466 cycles the discharge capacity had fallen from 602.3 to 594.7 mAh. This corresponds to a reduction of 1.3 % in the capacity. The cycle service life, defined as the number of cycles in which the discharge capacity is equal to 80 % of the original capacity, is thus significantly longer than when the customary method of charging is employed using a low pulsed current of C/10 or less.

**Example 3**
A nickel-cadmium accumulator, of AA size with a capacity of 600 mAh and a usual fast-charging time of 4 hours or more, was subjected to a cycle service life test in which, for every cycle, charging was carried out at 5 C, corresponding to a constant charge current of 3.0 A, and discharging was carried out at 2 C, corresponding to a discharge current of 1.2 A (to a discharge voltage of 0.5 V (100 % depth of discharge)). During charging, the maximum temperature, measured on the
outer wall of the accumulator, never reached the set temperature of 40 °C for the temperature safety cut-out. This test showed that after 1037 cycles the discharge capacity had fallen from 540 to 432 mAh. The cycle service life therefore corresponds to that when charging at C/10 or less.

Example 4
A nickel-cadmium accumulator, of AA size with a capacity of 600 mAh and a usual fast-charging time of 4 hours or more, was subjected to a cycle service life test in which, for every cycle, charging was carried out at 4 C, corresponding to a pulsed charge current of 2.4 A (charge pulse 1.4 s alternating with a 0.088 s pause without current) and discharging was carried out at 2 C, corresponding to a discharge current of 1.2 A.

This test showed that after 399 cycles the discharge capacity had fallen from 590 mAh to 546 mAh. The percentage fall (average) per cycle is consequently 0.02 %, which is appreciably higher than the decrease in the discharge capacity of 0.003 % per cycle in accordance with Example 2.

Example 5
A chargeable NiCd battery of AA size, with a nominal capacity of 600 mAh and a nominal charging time of 16 hours, was charged using a constant voltage (CV charging) of 1.85 V, after first having been charged and discharged three times in the conventional manner for 16 hours in the manner specified by the manufacturer. The charge current, starting at an initial value of about 9.5 A (which corresponds to charging at 16 C), showed, after a fall, a minimum after 5 minutes, after which a rise occurred. Integration of the charge current over the charging time of 5 minutes gave a charge capacity of 630 mAh. The discharge capacity was 560 mAh and the charge efficiency (the ratio of discharge capacity to charge capacity) was consequently 88.9 %.

Example 6
A chargeable NiCd battery of AA size, with a nominal capacity of 600 mAh and a nominal charging time of 16 hours, was charged using a constant voltage (CV charging) of 1.70 V, after having first been charged and discharged three times in the conventional manner for 16 hours in the manner specified by the manufacturer. The charge current, starting at an initial value of about 7 A (which corresponds to charging at 12 C), showed, after a fall, a minimum after 9 minutes, after which a
rise occurred. Integration of the charge current over the charging time of 9 minutes gave a charge capacity of 600 mA\(\text{h}\). The discharge capacity was 580 mA\(\text{h}\) and the charge efficiency was consequently 96.7 %.

Cycle service life experiments, with charging in accordance with Examples 5 and 6, showed no discernible decrease in the service life compared with that in the case of conventional charging over 14-16 hours.

It follows from Examples 5 and 6 that, in the case of CV charging, according to the invention, a very short charging time of 5-10 minutes can be achieved for accumulators which are not adapted for fast charging, and without adversely affecting the service life of the accumulator.

The battery heats up to only a slight extent during charging according to the invention. The temperature consequently remains well below the temperature for which the thermal safety cut-out is set (45 °C).

The high charge efficiency, coupled with the extremely short charging time and the low generation of heat, make the CV charging method, according to the invention, surprising.

In Examples 1-4, the voltage increase \(R\) was always calculated from seven successive accumulator voltages which were measured at equal time intervals. Using the shifting segment method, the voltage increase \(R\) can be calculated as follows:

\[
R = -3V_1 -2V_2 -V_3 +V_5 +2V_6 +3V_7.
\]

For Examples 5 and 6, the current decrease \(R\) was in each case calculated from seven successive charge currents, which were measured at equal time intervals. Using the shifting segment method, the charge current decrease \(R\) can be calculated as follows:

\[
R = -3V_1 -2V_2 -V_3 +V_5 +2V_6 +3V_7.
\]

The following conditions applied for all Examples 1-6:

When \(R\) reached a value of \(\leq 0\), fast charging was terminated immediately and the charging time and the charge efficiency were determined.
Claims

1. Method for charging an accumulator or battery, wherein a relatively high charge current is supplied to the accumulator and the charge current, or a voltage representative thereof, or the accumulator voltage is measured in order to follow the change in the charge current, or a voltage representative thereof, or the accumulator voltage during charging, and the point in time at which the accumulator is fully or essentially fully charged is determined, at which point in time charging is terminated or at least the charge current is appreciably reduced, and to which end, in order to determine the point in time during charging at which fast charging is terminated, the charge current, or a voltage representative thereof, or the accumulator voltage is measured successively at various points in time, and the data from, considered over time, the last N measurements, where N is at least 3, are used to calculate the increase or decrease in the charge current, or a voltage representative thereof, or the accumulator voltage R over time, using the following equation:

\[ R = \sum_{m=1}^{N} mV_m - \frac{1}{\sum_{m=1}^{N} m} \sum_{m=1}^{N} V_m \]

where \( V_m \) is the measured charge current or a voltage representative thereof, or the cell voltage, for an N-point segment;

until R falls below a predetermined threshold value, which determines the said point in time, wherein the charge current, or a voltage representative thereof, or the accumulator voltage, is measured either in the case of an essentially constant charge current or in the case of a charge current which is switched off for brief intervals.

2. Method according to Claim 1, wherein the predetermined threshold value for R is approximately 0 or negative, preferably less than 0.05 V and in particular less than 0.01 V.

3. Method according to Claim 1 or 2, wherein N is at least 5, preferably at least 7.

4. Method according to Claim 1, 2 or 3, wherein the temperature on the outside of the accumulator or battery is measured and fast charging is terminated when said temperature is about 35 °C or higher, preferably about 40 °C or higher.

5. Method according to one of the preceding claims, wherein
various accumulators are charged at the same time.

6. Method according to one of the preceding claims, wherein, prior to fast charging, at least one or all accumulators are discharged, preferably using a constant discharge current, down to a specific minimum discharge voltage.

7. Method according to one of the preceding claims, wherein a fast charge current of at least 3 C, preferably 4 C to 8 C, is used.

8. Installation for carrying out the method according to one of the preceding claims, provided with a time-determining element, an accumulator voltage measurement element, a switch device for successively actuating, at intervals, the charge current or accumulator voltage measurement element, a memory for recording, considered over time, at least the last N accumulator voltage measurements, a computer unit connected to the memory for determining, from the last N measured charge currents or accumulator voltages, the value of R, N being at least 3, and a switch element, connected to the computer unit, for actuating the fast charge circuit as a function of the value of R.
## INTERNATIONAL SEARCH REPORT

### A. CLASSIFICATION OF SUBJECT MATTER

**IPC 6** H02J7/10

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)

**IPC 6** H02J

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)

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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