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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01R 31/36, 31/04	A1	(11) International Publication Number: WO 98/48290 (43) International Publication Date: 29 October 1998 (29.10.98)

(21) International Application Number: PCT/NO98/00128

(22) International Filing Date: 22 April 1998 (22.04.98)

(30) Priority Data:
971841 22 April 1997 (22.04.97) NO

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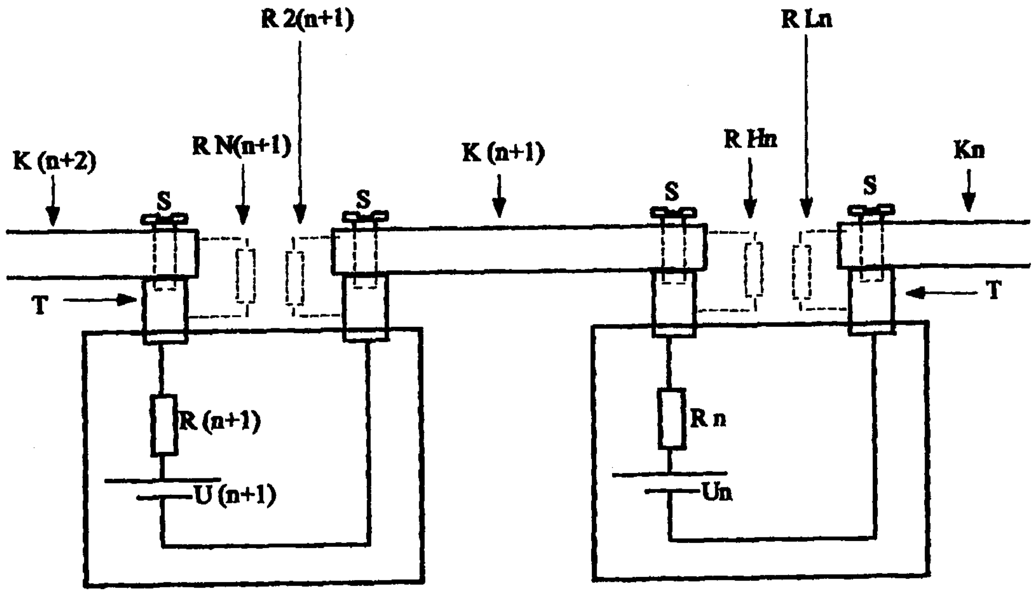
(81) Designated States: AU, CA, JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.
In English translation (filed in Norwegian).

(54) Title: MONITORING BATTERY CONDITION



(57) Abstract

In an accumulator battery, voltages are measured across every single cell. The voltage between the positive pole of a cell and the negative pole of the next cell of the series of connection is also measured. These voltage measurements are made for various currents through the battery. Based upon these measurements, it is possible to calculate the different equivalent resistances in the system: the equivalent internal resistance of each respective cell, as well as the resistance in the connection couplings between every cell in the battery. By means of these values it is possible to calculate the remaining capacity of each cell.

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MONITORING BATTERY CONDITION

The present invention describes a method for determining several important physical parameters of an accumulator battery.

This may e.g. relate to monitoring the operation of an accumulator battery in a submarine, a propulsion battery in a fork lift/electric motor car, or an emergency power battery.

Common to all these applications is that many single cells are interconnected in a series connection. When operating such a "series connection", it is very important that recharging and discharging are controlled and limited in accordance with the conditions of the particular single cell having the highest load. Further, the total properties of the battery will always be limited by the condition of the "poorest" cell. E.g. measuring the total voltage across the whole series connection, dividing this voltage by the number of cells in the battery, in order thereby to make a statement regarding the voltage across each single cell, may result in catastrophic consequences.

Batteries for which the present invention has been primarily conceived, consist of from 24 to 200 cells altogether in a series connection. Collecting measuring data from each respective cell traditionally requires very many cables, for example two single leads for every measurement parameter for each cell. Recording only temperature and voltages from a 24 cell battery will therefore immediately result in several hundred leads. This will soon become expensive and over-complex.

During recent years, measuring systems have appeared that are able to undertake such data acquisition using only a limited number of leads.

The present invention is based upon having available voltage measurements from all cells in the battery. A more detailed description of the invention shall hereby be given, with reference to the enclosed drawing.

Fig. 1 shows two interconnected single cells in a large battery. The cells are interconnected in series in the conventional manner by means of contact rails/leads. The drawing indicates rails to be screwed up to the pole terminals of single cells by means of a bolt.

In the coupling points there will always appear a coupling resistance. For the rest, we shall describe the single cell in the conventional manner, that is an ideal cell having an "equivalent internal resistance" connected in series.

Symbols:

Kn:	Interconnection conductor between cells n-1 and n in the series connection.
K(n+1)	Interconnection conductor between cells n and n+1.
S	Screw/bolt for connection conductor.
T	Pole terminals (positive or negative) for each cell.
RLn	Coupling resistance between conductor and negative cell pole of cell n.
Rhn	Coupling resistance between conductor and positive cell pole of cell n.
Rn	Internal resistance of single cell.
Un	"Open circuit voltage" of single cell.
	Fig. 2 shows how voltages are measured across single cells in the battery.
Un1	Is the voltage between the poles of cell n.
Un2	Voltage between negative pole of cell n and negative pole of cell (n+1).
I	Current through the series connection of cells.

The coupling resistances (RL.. and Rh..) should be as low as possible. However, it turns out that the coupling screws (S) may unscrew. Thereby a significant voltage drop may arise across this connection coupling. When the battery is discharged, this will have as a result a lower output voltage. When recharging the accumulator, this may have the result that the battery does not obtain a full charge. Further, heat will be generated in the coupling. This may start fires and explosions.

The voltage measurements (Un2 and Un1) are made directly between the pole terminals. By calculating the voltage difference (Un2 - Un1) one obtains the voltage drop across the conductor rail and the two screws. The current in the series connection is always known, so that the coupling resistance Rhn + RLn + 1 can be calculated.

The internal resistance Rn of the battery is also an interesting parameter. It is calculated in the conventional manner, by measuring voltage between the pole terminals, for two different currents through the cell. During operation of the battery, both in recharging and discharging, the equivalent internal resistance can be calculated in a simple manner for different current and current directions (recharging and discharging).

It turns out that this equivalent internal resistance is dependent on several parameters, like e.g. current, temperature and the age of the cell. Current and temperature dependence is common knowledge. Besides, it is common knowledge that the internal resistance increases in proportion to cell operating time.

The charge condition of the cell, or its capacity, is determined conventionally by measuring the specific weight of the cell electrolyte. This is quite an awkward procedure. There are no acceptable acid weight sensors available for connection to an automatic data acquisition system. Besides, in a valve controlled (gel) lead battery (or Nicad battery) there will be no liquid electrolyte. Determining remaining capacity in an accumulator is a large problem.

Empirically it turns out that the internal resistance of the cell is also dependent on the cell rest capacity (Cr). In a simplified manner, it can be expressed that the remaining capacity Cr is given by a function f

$$Cr=f(T,A,Rn,U,I,Rhl,Rnx,Cnx)$$

where T is temperature, A is total cell operating time, Rn is instantaneous, measured internal resistance, Rhl is sum resistance in the pole coupling points, U is cell open circuit voltage, and I is current through the cell.

Rnx is the internal resistance, and Cnx is the capacity when the cell was last defined to be fully charged.

All these parameters are measured in a simple manner. E.g. by using a data acquisition apparatus as mentioned in the introduction, this data capture does not entail large expenses.

We assume that the battery, in a close past, has been charged to full charge, and been discharged far down, so that the capacity Cnx was then estimated relatively well. During operation of batteries, these data are not hard to come by.

Several algorithms can be used to estimate the remaining capacity of cells. Mere extrapolations based on empirical data will give a result. Further, one may describe a battery cell mathematically, and thereby also calculate rest capacity.

In both of these calculating models, the most important parameter is the equivalent internal resistance of the cell. This internal resistance turns out to have a very predictable increase with decreasing charge/rest capacity in the battery. However, the internal resistance will also have a quite regular, predetermined increase as a function of the cell age and the number of times it has been recharged/discharged. The variation of the internal resistance with age and charge condition should in the future be regarded as one part of the cell specifications.

When using cost-effective data acquisition systems as described in the introduction, it is now possible to utilize the regularity and consequently predictability that is inherent in the various "equivalent resistances" of the battery.

For large batteries, e.g. submarine batteries, where tens of kAmperes may flow continuously, it is also important to take into consideration the equivalent resistances in the connection couplings between the single cells.

For such large currents it is also of course very important to monitor the resistance in the cell connection couplings. Even a small resistance here may result in a very significant voltage drop. In a worst case this may entail heat generation to such a large degree that a fire is started. A phenomenon like electric arcs is also a possible consequence of poor connections. The battery room in a submarine is often poorly ventilated, and oxyhydrogen gas is liberated during recharging, so that explosion is a not unknown phenomenon.

Some lead batteries, e.g. submarine batteries, must withstand large mechanical loads. If and electrode is loosened mechanically inside a battery cell, it may create a short-circuit in the cell. This may result in total loss of ship. When the battery is aged, material from one electrode will gradually be corroded away. This implies a reduction of the mechanical strength. Such a reduction of mechanical strength will be observed as an increase in internal resistance in the cell. With measurements as described, it will also be possible to monitor mechanical strength in each respective cell.

To understand the importance of monitoring every single cell in a battery, the following should be mentioned: The total battery output will depend on the weakest cell in the series. We know that there is some dispersion when manufacturing these cells. Further, e.g. lifetime and output are reduced quite significantly (10-50%) when the temperature is increased by merely 10 degrees. There will always be temperature gradients in a battery room, the cells standing in the centre of a block will of course be less cooled than the cells located outermost in the block. Also, "avalanche-effects" may arise in a battery. For example, the cells getting the highest temperatures, will have an increased internal resistance. This results again in increased heating if the current is maintained constant.

Finally it shall be mentioned that the internal resistance of the cell is not necessarily a purely ohmic resistance. By calculating the internal resistance of the cell for various current changes, frequences, amplitudes etc., the correct internal impedance of the cell can be determined. Experiences during later years may indicate that it may be possible, without knowing the cell history, to separate the remaining capacity of the cell and the influence of the cell age on the equivalent impedance of the cell. This seems to presuppose that we have an accurate measurement of the total internal complex impedance of the cell (merely ohmic resistance measurement is not sufficient).

PATENT CLAIMS

1. A method for monitoring the operation of batteries consisting of several single cells, where the battery is monitored by a data acquisition system able to measure temperature and voltage in each single cell, characterized in that voltage is measured between the negative and the positive pole terminal of every single cell, and correspondingly between the negative pole terminal of cell n in the series connection and the negative pole terminal of cell n+1 in the series connection, and that the coupling resistances between every cell is calculated on the basis of the current passing through the battery, and that the equivalent internal resistance of the cell is calculated on the basis of the change in cell voltage caused by a change in the current through the battery.

2. The method of claim 1, characterized in that all equivalent resistances in and between every cell is calculated on the basis of several different, known current values that are applied or tapped through the cell series connection.

3. The method of claim 1 and 2, characterized in that, based on empirical data for the battery cell in question or based on a mathematical model of the cell, together with measured temperature, measured cell voltage and calculated equivalent resistances, the instantaneous value of the remaining capacity in every battery cell is calculated.

4. The method of claim 1, characterized in that the interface resistance in the connection couplings between every cell in the battery is calculated continuously, based on the instantaneous value of the current, and that a warning is activated if this resistance changes rapidly or is outside predetermined values.

5. The method of claim 1 and 2,
c h a r a c t e r i z e d i n t h a t the cell internal resistance is used to estimate the mechanical strength of the cell.

6. The method of claim 1,
c h a r a c t e r i z e d i n t h a t an ac current having frequency, amplitude and shape that can be chosen, is superposed on the battery recharging current or discharging current, and that the different equivalent resistances of each cell are calculated on the basis of the changes caused by said ac current, and that based upon these calculations, an equivalent complex internal impedance is calculated.

7. The method of claim 6,
c h a r a c t e r i z e d i n t h a t the complex internal impedance of the cell is calculated and used to estimate the remaining capacity of the cell.

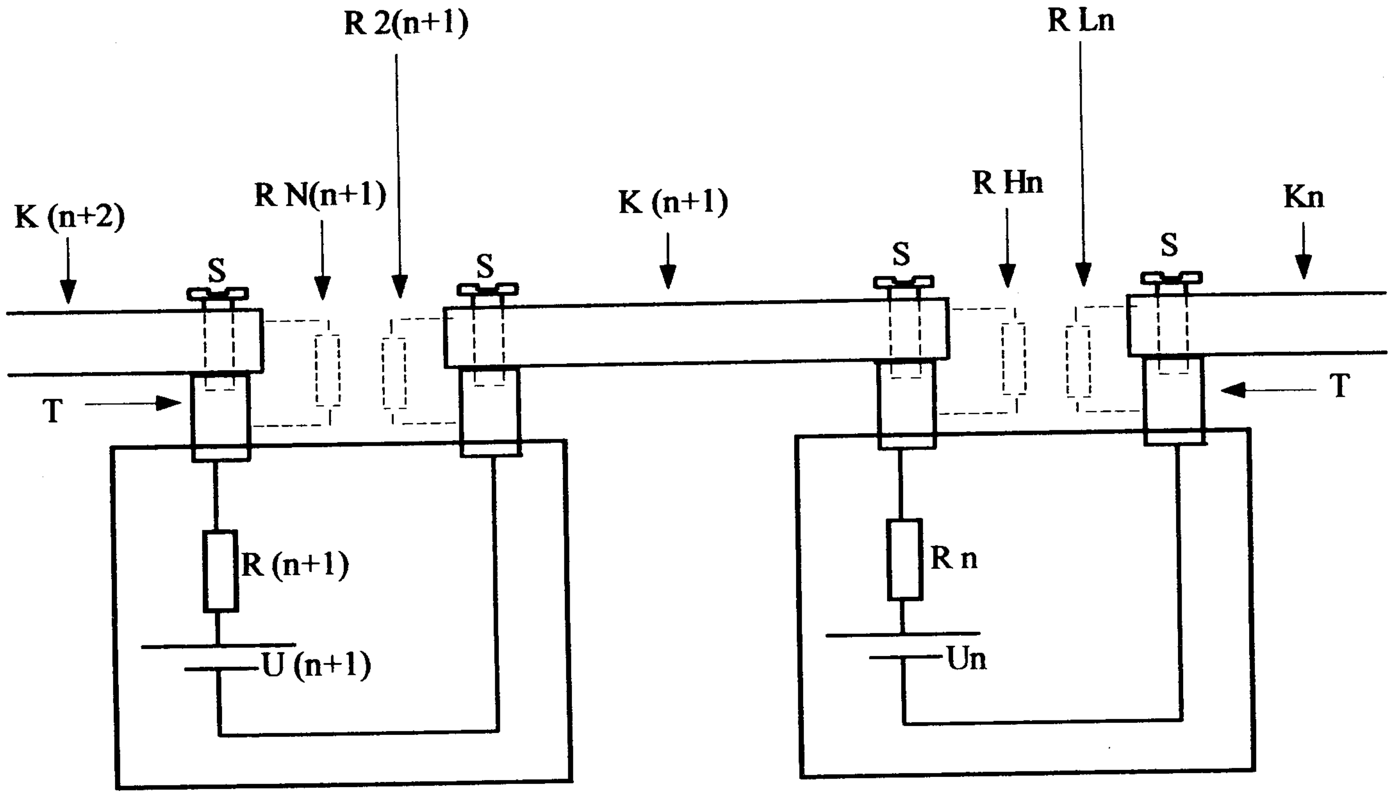

Fig. 1

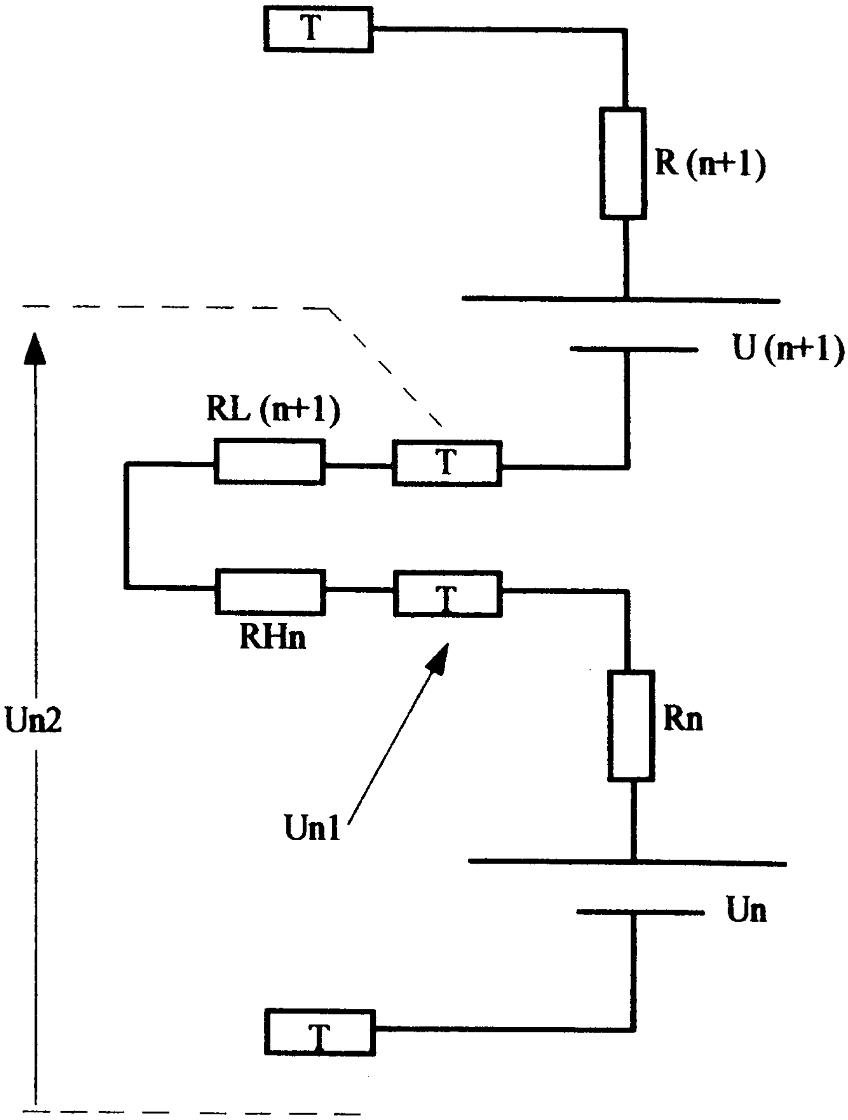

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 98/00128

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G01R 31/36, G01R 31/04
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)

IPC6: G01R, H02J, H01M

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

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 5546003 A (Z. NOWOROLSKI ET AL.), 13 August 1996 (13.08.96), column 1, line 60 - column 4, line 47 --	1-7
Y	US 5281920 A (J.W. WURST), 25 January 1994 (25.01.94), column 3, line 55 - column 4, line 4 --	1-7
A	DE 4408740 C1 (ACCUMULATORENFABRIK SONNENSCHEIN GMBH), 20 July 1995 (20.07.95), abstract --	1-7

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

27/07/98

International application No.

PCT/NO 98/00128

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