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(71) Applicant *(for DE only):* FORD WERKE A.G. [DE/DE]; Ottoplatz 2, Postfach 21 03 69, D-5000 Köln 21 (DE).

(71) Applicant *(for FR only):* FORD FRANCE S.A. [FR/FR]; B.P. 307, F-92506 Rueil Malmaison Cédex (FR).

(71) Applicant *(for JP only):* FORD MOTOR COMPANY [US/US]; County of Wayne, Dearborn, MI 48120 (US).

(71) Applicant *(for all designated States except DE FR JP US):* FORD MOTOR COMPANY LIMITED [GB/GB]; Eagle Way, Brentwood, Essex CM14 4AA (GB).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)* : STFFENS, Willi [DE/DE]; Jagerstr. 17-19, D-5100 Aachen (DE).

(74) Agent: MESSULAM, A.; 24 Broadway, Leigh on Sea, Essex SS9 1BN (GB).

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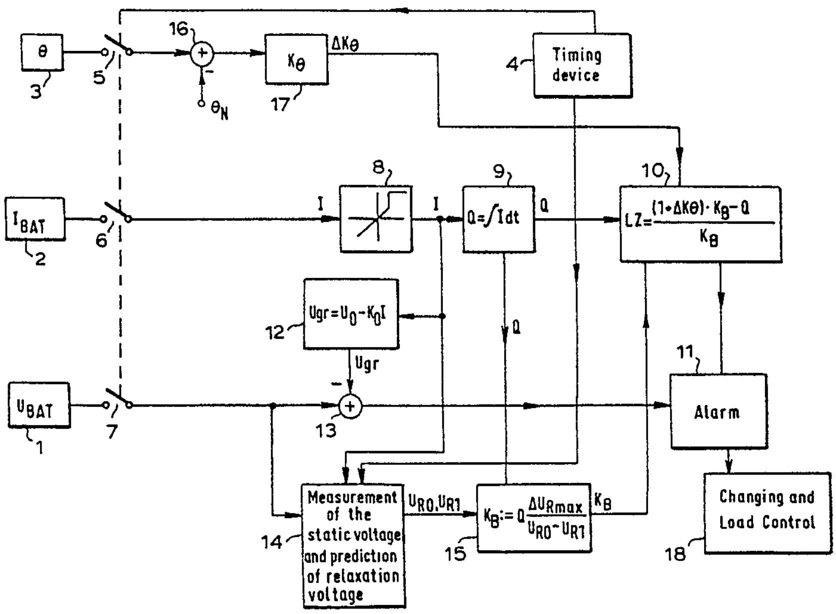

(57) Abstract

In order to monitor continuously the state of charge of a battery, the relaxation voltage of the battery is measured directly, or predicted from measurements taken with no current or only a small current flowing through the battery. From the relaxation voltage, the notional state of charge of the battery, prior to switching on of significant loads or of a charging device, is calculated. During later operation, with the loads and/or charging device in use, the current drawn from or fed to the battery is constantly measured and integrated and the state of charge is continuously estimated from the result of the integration and the notional state measured with the battery previously at rest.

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MONITORING STATE OF BATTERY CHARGE

The invention relates to a method and apparatus for monitoring the state of charge of a storage battery. The invention is particularly applicable to monitoring the charge in a motor vehicle and is described below by reference to such an embodiment.

Lead acid accumulators are often used as the starter batteries of motor vehicles powered by internal combustion engines. The starter battery during engine starting supplies current to a starter motor temporarily coupled to the engine. After starting the internal combustion engine, the storage battery is recharged by a generator or alternator driven by the internal combustion engine.

When the vehicle is stationary, the starter battery may also power a parking light as well as loads of lower power consumption such as an electric clock in the vehicle and other monitoring devices.

Studies have shown that in the great majority of cases, the alternator can meet the current requirements of the various loads during normal usage of the vehicle and can also recharge the battery to compensate for the loss of charge during starting provided that the vehicle is not used exclusively for short journeys, with very frequent stopping and starting, or for long periods with all the electrical loads switched on. It is also necessary for the battery, in the event of a sudden failure of the generator, to be able to continue for a limited period to provide power for the ignition system of the internal combustion engine.

In addition to the standard electrical features such as the lights and the windscreen wipers, the battery must when necessary also supply electrical power to electrical loads such as for example an antilocking system for the vehicle brakes, automatic vehicle speed control (cruise control) etc., since their sudden failure would pose a considerable to risk to safety, and such loads are becoming increasingly common in modern vehicles.

It is therefore becoming ever more necessary to monitor the state of charge of the battery continuously and to warn the driver in good time when the state of charge of the battery threatens to drop to a critical level.

Hitherto motor vehicles, in particular passenger cars, have not had any device at all for indicating the state of charge of the starter battery. At best, they have made do with a voltmeter which provides little information on the actual state of charge. It is of course possible to monitor the state of charge of the battery by checking the density of the acid after the battery has been unused for a period of some hours, but this is inaccurate under dynamic conditions and awkward to do on a regular basis and therefore is of little practical value.

In theory, the state of charge of the battery may be determined by measuring and integrating the discharge or charge current over time and comparing the result with the battery capacity. Such a method, however, would break down on account of the variability of the battery capacity and its dependence upon the strength of the current drawn.

During each starting procedure, the starter battery is subjected to a momentary loading with a high discharge current, in which the diffusion in the battery cells does not keep pace with the acid consumption. The greater the strength of the current, the sooner the storage battery is run down and the smaller its actually usable capacity becomes. If on the other hand the storage battery is discharged at intervals, giving the acid in the cells time in which in can balance itself out again, recovery takes place and the capacity is greater. It is also possible after the battery has been run down by discharging it with high current, to continue to discharge it further with a reduced strength of the current as the reduced current necessitates a reduced diffusion.

The present invention seeks to provide a method and apparatus for monitoring the state of charge of a storage battery, in particular the starter battery of a motor vehicle, which can continuously monitor the state of charge under widely varying operating conditions in a simple manner, can be implemented inexpensively, and can provide a timely indication when the state of charge of the battery is low so that a warning may be given to the driver or remedial action may be taken automatically.

According to a first aspect of the present invention, there is provided a method of monitoring the state of charge of a storage battery, which comprises the steps of :

a) measuring a voltage indicative of the relaxation voltage, as herein defined, of the battery to provide an indication of the state of charge,

b) storing reference data representative of the state of charge as represented by the relaxation voltage,

c) measuring the current flowing through the battery when a charging means and/or significant loads are switched on and integrating the measured current to provide an indication of the charge loss or gain following the measurement of the relaxation voltage, and

d) continuously estimating the available remaining charge from the stored reference data and the result of the integration.

Preferably, in estimating the remaining charge, other operating parameters of the battery, such as temperature, are taken into consideration.

When a battery is allowed to stand with minimal current being taken from it after a period of use, the output voltage of the battery measured in a substantially open circuit will drift towards a steady state value after some time and this is herein referred to as the relaxation voltage.

The relaxation voltage has been found to be a reliable indication of the remaining charge and within acceptable limits does not vary with battery age. If the battery was being discharged prior to relaxation, the output voltage rises steadily at first and later approaches its steady state value asymptotically. Conversely, if the battery was being charged prior to relaxation, then the voltage will start higher than the relaxation voltage and will drop towards the steady state value, this time with a longer time constant. If no current at all is take from the battery, then the steady state may not be reached for several five hours after discharging and even longer after charging. However, the relaxation time is reduced significantly if a small predetermined current is taken from the battery.

The present invention is predicated upon the appreciation that the relaxation voltage may be measured or estimated regularly to provide a reference value with which the charge taken from the battery can be compared. The integration of current alone is unreliable because of the cumulative errors which occur for example on account of the fact that the discharging effect is dependent upon the magnitude of the current. However, if the stored reference is updated a regular intervals then the subtraction of the calculated charge drawn from the battery from the previously estimated available charge provides a more accurate continuous indication of the state charge and any cumulative errors in the integration are automatically corrected by each direct measurement of the relaxation voltage.

In a second aspect of the invention, there is provided a method of monitoring the state of charge of a storage battery of a motor vehicle, which method comprises the steps of :

(a) measuring the open circuit battery voltage when the engine is stopped and no significant current or a predetermined minimum current is drawn from the battery, calculating from the measured voltage a relaxation voltage, and evaluating a notional remaining battery capacity from the difference between the calculated relaxation voltage and the relaxation voltage of a fully charged battery,

(b) continuously measuring and time integrating the current flowing through the battery during operation of the vehicle engine to determine the charge drawn from the battery, and

(c) subtracting the charge withdrawn during engine operation from the notional battery capacity calculated during the previous stoppage of the engine to determine the available charge remaining in the battery.

When used in a motor vehicle the method of the invention ensures a repeated correction of the calculation of the capacity each time the vehicle engine is switched off for a time and thus provides, virtually independently of the level of the discharge flow, a reliable indication of the actual state of charge, which may readily easily be utilized to produce an alarm or control signal when a predetermined minimum state of charge is detected.

Advantageously, the temperature of the starter battery is measured continuously and is included in the detection of the state of charge as a correction value for the notional battery capacity. In this way the range of error is additionally limited while monitoring the state of charge and the effect of different ambient temperatures is minimised.

According to a further feature of the invention, to compensate for the dependence of the battery capacity upon the magnitude of the drawn current, a current dependent critical voltage may be derived from the voltage of the fully charged battery and the measured magnitude of the discharge current and the critical voltage may be compared with the constantly measured battery voltage to provide a warning or control signal.

The current measurements are carried out preferably at regular intervals during operation, in a predetermined timed sequence.

The computed remaining charge may be used not only to provide a warning indication but may be used to determine the recharge cycle and the charging rate when the engine is next turned on.

Because the method of the invention requires storage of data, comparison and integration over long periods of operation it lends itself well to implementation using digital techniques and is preferably carried out under micro-processor control. The micro-processor may be dedicated to this function or use may be made of a micro-processor serving other functions such as engine management or brake control.

The invention further provides apparatus as set forth in the claims for implementation of the method described above.

The invention will now be described further, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a block circuit diagram of an apparatus for performing the method according to the invention, and

Figure 2 is a diagram for illustrating the course of the off-load voltage of a lead storage battery as a function of the amount of current drawn from the battery.

Initial values for measuring and monitoring the state of charge of a starter battery (not shown in the drawing) are the battery voltage U_{BAT}; the battery current I_{BAT} (which is assumed to be positive during discharging and negative during charging) and; the battery temperature θ(which in practice is substantially the same as the ambient temperature of the battery installation).

In Figure 1, the above-mentioned values U_{BAT} and I_{BAT} are recorded by measuring devices which are allocated the reference numerals 1 for the battery voltage, 2 for the battery current and 3 for the battery temperature and are converted into analogue or digital electrical signals which are passed on by a timing device 4 at, for example, one second intervals by way of switching devices 5, 6 and 7 respectively to the individual elements of an electronic apparatus for monitoring the state of charge of the battery.

The current signal I corresponding to the battery current I_{BAT} is first pre-amplified in an amplifier 8 and is then integrated in an integrator 9 with respect to time in accordance with the equation

$$Q = \quad I \, . \, dt \qquad \text{(Eq. 1).}$$

The charge thereby obtained is supplied to a calculator unit 10 which calculates the state of charge, expressed as a percentage LZ of the full charge, in accordance with the equation

$$LZ = \frac{(1 + \Delta K_\theta)K_B - Q}{K_B} \times 100 \, [\%] \qquad \text{(Eq. 2)}$$

in which K_B is the battery capacity and Q, depending upon the polarity sign, is the total charge drawn or resupplied, both measured in ampere hours, and ΔK_θ is a temperature-dependent factor which is explained below.

If the state of charge drops to a critical value, a signal is supplied by the calculator unit 10 to an alarm 11 which warns the driver of this condition in a suitable manner, for example by means of a warning light and/or an audible signal. Alternatively, the output of the calculator unit 10 may automatically adapt the vehicle electronic loads and/or the recharge cycle and charging rate.

In one possible strategy, the voltage regulation may be first adapted to increase the recharging rate to compensate for excessive loading and if the charge in the battery continues to drop then load circuits may be sequentially disabled, in accordance with a set order of priority in order to ensure that adequate charge should remain for the circuits essential to the safe continued operation of the vehicle.

The control of the voltage regulation need not only be carried out in response to an unduly low remaining charge but may be used to reduce the load placed by the generator on the engine by disengaging the drive to the generator or driving the generator under no load conditions when the remaining charge exceeds a preset level. This can increase operating efficiency by removing the drag on the engine at times when the current requirements of the vehicle can be met from the stored battery charge alone.

The voltage signal U generated by the battery voltage U_{BAT} is employed in two ways in monitoring the state of the battery. In the first place it is used to trigger a signal in the alarm 11 when the remaining charge drops below a current-dependent critical voltage U_{gr}. This critical value U_{gr} is calculated in a critical voltage calculator 12 from a given initial voltage U_o and the current signal I and a constant K_o according to the equation :

$$U_{gr} = U_o - K_o.I \qquad \text{(Eq. 3)}$$

and is then substracted from the signal voltage U in a subtraction unit 13. The difference is passed on to the alarm 11 and triggers the latter on dropping to a predetermined minimum value irrespective of the state of charge detected in the calculator unit 10.

The voltage signal U is further supplied to a voltage recording unit 14 which is connected to a capacity calculating unit 15. The voltage recording unit 14 starts by registering the fact that either no current or a current not exceeding a low threshold value is flowing through the battery. If this state persists for a prolonged period of time, say a minimum of one hour, then the voltage and its rate od change are measured at this moment and are used to make a prediction of the relaxation voltage U_{R1}, this being the steady value of the voltage if enough time were allowed for relaxation. The predicted relaxation voltage is then passed to capacity calculating unit 15 to enable a theoretical battery capacity to be evaluated and this is passed on to the calculating unit 10 . as a factor K_B for computation of the charge state.

The time required for the voltage to reach a steady state can be considerably reduced by drawing a minimal current from the battery rather than no current at all and it is preferred to draw such a minimal current in order to increase the ease of measurement and prediction of the relaxation voltage. This minimal current is usually determined by the vehicle electronic accessories such as clocks, radios and trip computers. The prediction of the relaxation voltage need not be based on a single reading and it may instead be possible to plot the variation of the rest voltage with time and to correlate the resulting meaurement graph with corresponding calibration graphs prepared for batteries with a known remaining charge.

Computation of the theoretical battery capacity in the capacity-calculating unit 15 from the relaxation voltage predicted in the unit 14 is based on the known fact that between the acid density of the battery after relaxation, which is considered to be a measure of the state of charge of the battery, and the relaxation voltage there is a relationship which can be used to determine the actual state of charge of the battery. This correlation is shown in the graph of Figure 2.

Starting with the relaxation voltage U_{R0} of the fully charged battery there is a substantially linear correlation between the charge Q drawn and the relaxation voltage U_R up to the maximum charge Q_{max} which can be drawn and which is equal to the capacity K_B of the battery. Tests on a number of different lead accumulators have shown that the minimum rest voltage U_{Rmin}, corresponding to maximum discharge of the battery ($Q_{max} = K_B$) is approximately equal to $0.9.U_{RO}$.

With the help of the following equation, derived from the linear correlation represented in Figure 2,

$$U_{R1} = U_{RO} - Q_1 \cdot \frac{U_{RO} - U_{Rmin}}{K_B} \qquad \text{(Eq. 4)}$$

and the relationship

$$U_{Ro} - U_{Rmin} = \Delta U_{Rmax} \qquad \text{(Eq. 5)}$$

the theoretical battery, after appropriate conversion and incorporation of the charge Q passed from the integrator 9 to the capacity calculating unit 15, is calculated from the following equation :

$$K_B = Q \cdot \frac{\Delta U_{Rmax}}{U_{RO} - U_{R1}}, \qquad \text{(Eq. 6)}$$

in which U_{RO} is the relaxation voltage measured in the fully charged state of the battery by means of the relaxation voltage measuring device 14 and stored in the capacity-calculating unit 15.

On closer examination of equation 6, one can see that it is only possible to re-compute the theoretical battery capacity K_B when $Q > 0$ and $U_{R1} < U_{R0}$.

Recording the course of the battery voltage and the battery current is not sufficient, however, for determining the charge state under greatly varying battery temperatures, since the battery temperature θ brings a considerable influence to bear on the charge state of the battery. It is therefore necessary, as mentioned in connection with Equation 1, to take into consideration a temperature factor K_θ when calculating the state of charge in the calculator unit 10, which is passed on by the temperature measurement device 3.

It is known that the capacity of a lead acid accumulator varies by approximately 1% per degree Celcius within the temperature range of 0^oC to 40^oC. Starting with a nominal temperature θ_N, which in vehicle batteries is set at 30^oC, the battery capacity increases with higher temperatures and drops accordingly at temperatures lower than 30^oC.

The temperature signal produced by the temperature measurement transducer 3 is therefore, after a signal corresponding to the nominal temperature θ_N has been subtracted in a substraction unit 16, supplied to a correction factor calculator unit 17, which calculates the correction factor ΔK_θ already mentioned according to the equation

$$\Delta K_\theta = K_\theta . (\theta - \theta_N) \qquad \text{(Eq.7)}$$

where K_θ may be taken as $.01/^oC$, and passes it on to the calculator unit 10.

The apparatus schematically illustrated by a block circuit diagram in Figure 1 for evaluating the battery voltage, the battery current and the battery temperature and for determining and monitoring the state of charge of the battery can readily translated into an electronic circuit by the person skilled in the art, where the measurement devices are appropriately combined with analog/digital converters since the analogous signal processing can be carried out digitally using a micro-processor. If an 8-bit conversion is employed, the resulting low resolution can necessitate omission of the start-up current from the current calculation. In order to take account of the start-up operation, a mean start-up current can be assumed and a time measurement alone can be relied upon to indicate the total loss of battery charge during starting.

CLAIMS

1. A method of monitoring the state of charge of a storage battery, which comprises the steps of :

a) measuring a voltage indicative of the relaxation voltage, as herein defined, of the battery to provide an indication of the state of charge,

b) storing reference data representative of the state of charge as represented by the relaxation voltage,

c) measuring the current flowing through the battery when a charging means and/or significant loads are switched on and integrating the measured current to provide an indication of the charge loss or gain following the measurement of the relaxation voltage, and

d) continuously estimating the available remaining charge from the stored reference data and the result of the integration.

2. A method as claimed in claim 1, wherein in estimating the remaining charge, other operating parameters of the battery, such as temperature, are taken into consideration.

3. A method of monitoring the state of charge of a storage battery of a motor vehicle, which method comprises the steps of :

(a) measuring the open circuit battery voltage when the engine is stopped and no significant current or a minimal current is drawn from the battery, calculating from the measured voltage a relaxation voltage, and evaluating a notional remaining battery capacity from the difference between the calculated relaxation voltage and the relaxation voltage of a fully charged battery,

(b) continuously measuring and time integrating the current flowing through the battery during operation of the vehicle engine to determine the charge drawn from the battery, and

(c) subtracting the charge withdrawn during engine operation from the notional battery capacity calculated during the previous stoppage of the engine to determine continuously the available charge remaining in the battery.

4. A method as claimed in claim 3, wherein the temperature of the battery is measured continuously and is included in the detection of the state of charge as a correction value for the notional battery capacity.

5. A method as claimed in claim 2 or 3, wherein a current dependent critical voltage is derived from the voltage of the fully charged battery and the measured magnitude of the discharge current and the critical voltage is compared with the constantly measured battery voltage to provide a warning indication.

6. A method as claimed in any of claims 3 to 5, wherein the computed state of charge of the battery is used to determine the recharge cycle and the charging rate when the engine is next turned on.

7. An apparatus for performing the method according to any one of Claims 1 to 6, comprising measuring means (2,1) for the continuous measurement of the battery current (I_{BAT}) and the battery voltage (U_{BAT}); an integrator (9) connected to the current-measuring means (2) for determining the charge (Q) drawn from the battery, a device (14) connected to the voltage-measuring device (1) and controllable by the current-measuring device (2) for determining the relaxation voltage (U_{RI}) occurring after a minimal current has been drawn from the battery for a predetermined period, means (15) for

calculating a notional battery capacity (K_B) from the relaxation voltage (U_{RI}) and the charge (Q_1) drawn from the battery, and a means (10) for comparing the drawn charge (Q), which the integrator (9) continuously determines when the battery current (I_{BAT}) flows again, with the calculated notional battery capacity (K_B), and thus for continuoulsy determining the state of charge (LZ).

8. An apparatus according to Claim 7, comprising an alarm (11) connected to the means (10) for comparing the charge withdrawal (Q) with the notional battery capacity (K_B) and arranged to provide a warning or control signal when the state of the battery charge drops below a predetermined level.

9. An apparatus according to Claim 7 or 8, further comprising a device (3) for continuously measuring the battery temperature for forming a correction value (ΔK_θ) for the notional battery capacity from the comparison of the measured temperature (θ) with predetermined nominal temperature (θ_N).

10. An apparatus according to any on of Claims 7 to 9, further comprising means (12) for continuously determining a maximum value (U_{gr}) dependent upon the discharge current (I) for the battery voltage falling with the discharge, and a device for comparing this voltage (U_{gr}) with the continuously measured battery voltage (U).

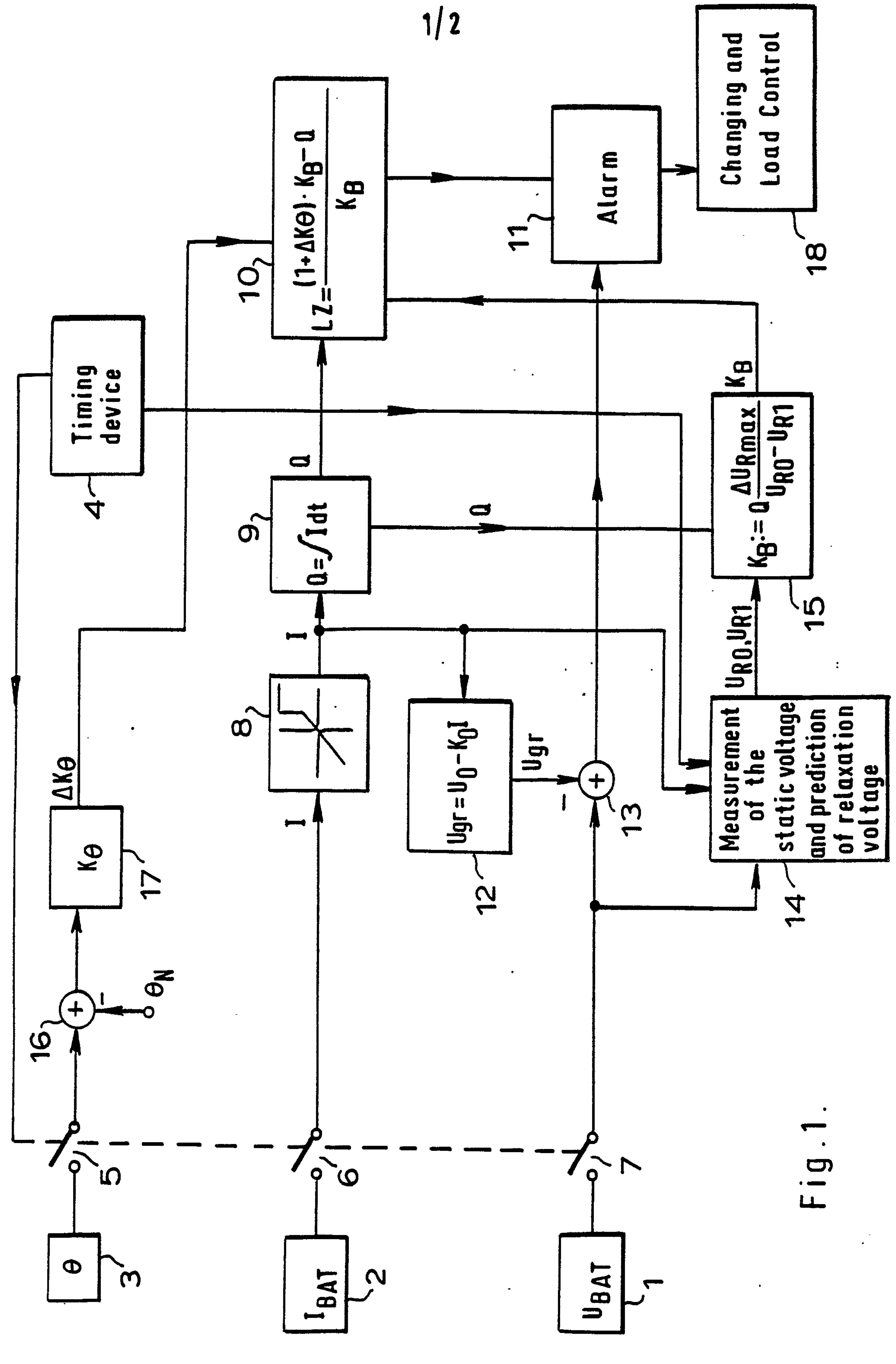
Changing and Load Control
Alarm
$LZ = \frac{(1+\Delta K\theta) \cdot K_B - Q}{K_B}$
Timing device
$Q = \int I dt$
$K_B := Q \frac{\Delta U_{Rmax}}{U_{R0} - U_{R1}}$
K_B
Q
U_{R0}, U_{R1}
Measurement of the static voltage and prediction of relaxation voltage
$U_{gr} = U_0 - K_0 I$
U_{gr}
I
$\Delta K\theta$
$K\theta$
θ_N
θ
I_{BAT}
U_{BAT}
1
2
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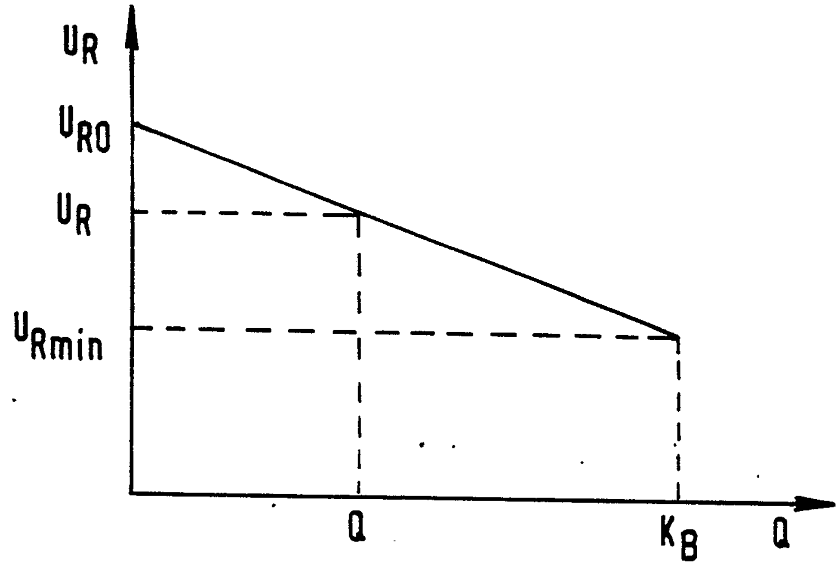
Fig.1.



$$\Delta U_{Rmax} = U_{R0} - U_{Rmin}$$

Fig. 2.

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 86/00290

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC[4]: H 02 J 7/14; G 01 R 31/36

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC[4]	H 02 J; G 01 R

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	US, A, 4333149 (D. TAYLOR) 1 June 1982, see abstract; column 4, lines 2-16; column 5, lines 11-35; figure 1 --	1,3,7,8
Y	DE, A, 3116371 (L. HORN) 2 february 1983, see abstract; page 6, lines 1-5; figure --	1,3,7,8
A	US, A, 4377787 (T. KIKUOKA) 22 March 1983, see abstract; figure 1 --	2,4,9
A	US, A, 4234840 (C. KONRAD ET AL.) 18 November 1980, see abstract; column 4, lines 3-47; column 6, line 43 - column 7, line 24; figures 1,3 --	1,10
A	EP, A, 0079788 (CURTIS INSTRUMENTS) 25 May 1983, see page 1, line 14 - page 2, line 4; page 2, lines 9-18; page 4, line 20 - page 5, line 14; page 5, line 21 - page 6, line 5; figures 1,2 --	1
A	US, A, 3617850 (E. DOMSHY) 2 November 1971, see abstract; column 4, lines 28-31, figure 1	6

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
29th August 1986	15 OCT 1986
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	M. VAN MOL

Form PCT/ISA/210 (second sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO. PCT/GB 86/00290 (SA 13379)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 19/09/86

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4333149	01/06/82	None	
DE-A- 3116371	17/02/83	None	
US-A- 4377787	22/03/83	JP-A- 56028476	20/03/81
US-A- 4234840	18/11/80	None	
EP-A- 0079788	25/05/83	US-A- 4560937	24/12/85
US-A- 3617850	02/11/71	None	

For more details about this annex :
see Official Journal of the European Patent Office, No. 12/82