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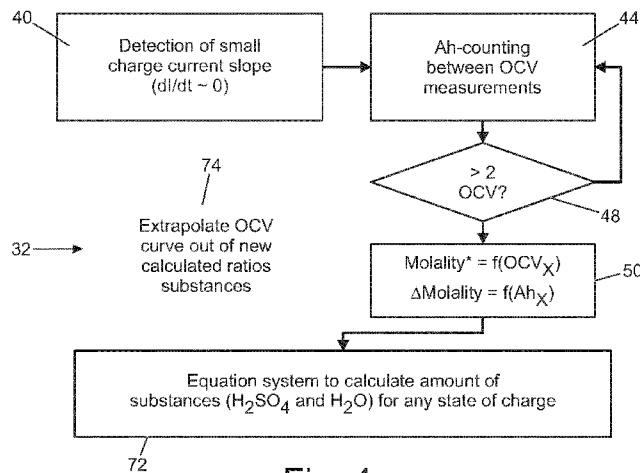


Fig. 4

(57) Abstract: A battery monitoring system (12) for monitoring the capacity or capacity loss of a lead-acid vehicle battery (10) comprising an electrolyte of acid and water, the battery having a charging phase during which a charge level of the battery is increased, a discharging phase during which the charge level of the battery is decreased and a measurement phase during which measurements are taken to determine the capacity. The battery monitoring system (12) comprises; a measurement device for measuring, during the measurement phase, at least first and second open circuit voltage (OCV) measurements from the battery (10) when no load is being driven by the battery, the OCV measurements being taken at first and second charge levels, respectively, and a processor configured to predict a minimum OCV corresponding to a minimum charge level of the battery (10) on the basis of the first and second OCV measurements; and to determine the capacity or capacity loss of the battery (10) on the basis of the first and second OCV measurements and the minimum OCV.

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BATTERY MONITORING SYSTEM FOR LEAD-ACID BATTERY
BASED ON MOLALITY OF ACID

TECHNICAL FIELD

5 The present disclosure relates to a vehicle battery monitoring system for determining the capacity loss, or capacity, of the battery, and particularly a lead-acid battery. In particular, but not exclusively, the invention relates to a battery monitoring system for a hybrid or micro-hybrid vehicle where the battery is used repeatedly, during normal use, to re-start the engine after a temporary stop. Aspects of the invention also relate to a
10 method of monitoring a vehicle battery and to a vehicle provided with a battery monitoring system.

BACKGROUND

15 In traditional vehicles having a combustion engine as a source of motive power, a battery is used to initiate starting of the engine and to crank the engine, and to supply and regulate power to various electrical functions within the vehicle. In a hybrid vehicle (often referred to as a hybrid electric vehicle), there are two sources of power to provide vehicle propulsion: a combustion engine and an electric motor which is
20 powered by a battery. At low vehicle speeds the vehicle is propelled only by the electric motor, with the engine being reserved for higher speed driving. In micro-hybrid vehicles, the battery is just used to initiate engine starting and to crank the engine, and to supply power the electrical functions, but does not provide a source of traction.

25 Micro-hybrid vehicles are typically provided with a stop-start functionality which allows the engine to be turned off when the vehicle is brought to a temporary halt (e.g. at traffic lights) and the electric motor powered by the battery is used to re-start the engine. For hybrid vehicles the equivalent stop-start function is called electric drive where the combustion engine can be stopped and started without the vehicle being
30 stationary. Such vehicles are also provided with regenerative braking systems which harness energy from the braking function for storage or re-use, rather than losing the energy as heat through braking friction. Hybrid and micro-hybrid vehicles are therefore increasingly popular for their excellent fuel economy and low CO₂ emissions.

Typically the batteries used in vehicles are lead-acid batteries which have an initial, full capacity, and slowly degrade over time a result of sulfation which is a product of the battery discharge reaction. Water loss and other ageing effects also contribute to degradation. The sulphate crystals can be dissolved through the charging process, but
5 the extent to which this is possible depends on the solubility of the crystals which decreases over time.

It is important to be able to determine the state of health of the battery (i.e. the extent of sulfation) so as to ensure measures can be taken to counter the loss of battery
10 capacity. For example, it is important that the available capacity is never allowed to decrease to a level which would not permit the hybrid vehicle to be re-started after a stop event, and to ensure there is sufficient electrical power to drive the various electrical functions in the vehicle. Sometimes it is necessary to modify the use of various functions of the vehicle depending on the battery capacity. The monitoring of
15 battery capacity, both power and energy deliverability, is particularly important in hybrid or micro-hybrid vehicles having a stop-start function where the battery is required to re-start the engine after a temporary shut-down, so as to avoid situations where the vehicle become stranded.

20 One known technique for monitoring the state of health of a battery requires the battery capacity to be checked 'off-line' when the vehicle is not in use. However, this is inconvenient for the user and does not necessarily avoid the inconvenience of the vehicle becoming stranded, with no means to re-start the engine and/or the motor, if a battery check is scheduled too late. Other known techniques can be carried out 'real-
25 time', when the vehicle is in use, and are much preferred because they allow continual monitoring of the battery state of health. However, current real-time techniques rely on a measurement of resistance based on current and voltage measurements and such measurements suffer from a low signal to noise ratio, particularly when the battery is at higher charge levels, and so the methods are not entirely accurate. These methods
30 can be improved by discharging the battery slightly before the current and voltage measurements are taken, but this runs the risk of the battery reaching too low a level of discharge to be recharged again, and so again risks the vehicle becoming stranded.

It is one object of the invention to provide a battery monitoring system which addresses the aforementioned problems.

SUMMARY OF THE INVENTION

5

Aspects and embodiments of the invention provide a battery monitoring system, a method of monitoring the capacity of a vehicle battery, and a vehicle comprising the battery monitoring system as claimed in the appended claims.

10 According to one aspect of the invention, there is provided a battery monitoring system for monitoring the capacity or capacity loss of a lead-acid vehicle battery comprising an electrolyte of acid and water, the battery having a charging phase during which a charge level of the battery is increased, a discharging phase during which the charge level of the battery is decreased and a measurement phase during which
15 measurements are taken to determine the capacity or capacity loss of the battery, the battery monitoring system comprising a measurement device for measuring, during the measurement phase, at least first and second open circuit voltage (OCV) measurements across terminals of the battery when no load is being driven by the battery, the first and second OCV measurements being taken at first and second
20 charge levels, respectively. A processor is provided with an algorithm configured to predict a minimum open circuit voltage (OCV) corresponding to a minimum charge level of the battery on the basis of the first and second OCV measurements and to determine the current capacity and/or capacity loss of the battery on the basis of the first and second OCV measurements and the minimum OCV.

25

The invention provides an advantage over the known techniques for determining the capacity loss of a vehicle battery because it can be used during normal vehicle use, without the need for the vehicle to be taken to a garage for servicing. Furthermore, all that is required for the method is a minimum of two independent OCV measurements
30 at different state of charge (SoC) levels. Measurements are scheduled to be taken during the measurement phase when the vehicle has come to a temporary stop (e.g. overnight). This is made possible because the battery does not need to be fully discharged in order to make the measurements. Some existing techniques which require a full or near full battery discharge in order to ascertain battery health are not

suitable for use in normal vehicle use and require garage servicing to implement them. Alternatively, those methods which can be implemented in normal vehicle use present a risk to the vehicle driver that the full battery discharge may lead to a failure to re-start the engine after the measurement phase.

5

The invention is particularly advantageous when implemented in a hybrid or micro-hybrid vehicle, particularly one with a start-stop functionality, where the battery is repeatedly required to re-start the engine after a temporary halt. In such vehicles it is especially important that good state of battery capacity is maintained and loss of capacity is monitored so as to avoid situations where the battery fails to re-start the engine after a temporary halt.

In one embodiment, the measurement device measures at least first, second and third open circuit voltage (OCV) measurements at first, second and third charge states respectively. The processor may be configured to predict the minimum OCV on the basis of the first, second and third OCV measurements.

The use of three independent OCV measurements to predict the minimum OCV improves the accuracy of the prediction. Further OCV measurements improve the accuracy still further.

The processor may be configured to determine the capacity loss of the battery based on the current capacity of the battery and a pre-determined initial capacity of the battery.

25

The processor may be configured to determine the concentration of the water and/or acid in the battery based on at least the first and second OCV measurements in order to predict the minimum OCV.

In one embodiment of the invention, the processor may also be configured to predict the minimum OCV by extrapolation based on at least the first and second OCV measurements.

The processor may also be configured to determine an extrapolated value of the molality of acid at the minimum charge level and to predict the minimum OCV by extrapolation based on the determined extrapolated value of the molality of acid.

- 5 The processor may also be configured to measure the first OCV measurement at a first relatively low charge level and to measure the second OCV measurement at a second charge level higher than the first charge level.

10 The processor may also be configured to measure the first OCV measurement at a first relatively high charge level and to measure the second OCV measurement at a second charge level lower than the first charge level.

15 The battery monitoring system may use first and second charge levels that are at least 80% of a maximum charge level of the battery. A benefit of the invention is that the battery need not be discharged to any significant level in order to determine the capacity/capacity loss.

The battery monitoring system may be configured to control at least one vehicle electrical function on the basis of the determined current capacity of the battery.

20 The battery monitoring system may be configured to measure the first and second OCV measurements during two separate measurement phases (e.g. occurring at different times and even on different days) when the vehicle is parked.

25 According to another aspect of the invention, there is provided a method of monitoring the capacity of a lead-acid vehicle battery comprising an electrolyte of acid and water, the battery having a charging phase during which a charge level of the battery is increased, a discharging phase during which the charge level of the battery is decreased and a measurement phase during which measurements are taken to
30 determine the capacity. The method may comprise; measuring at least first and second open circuit voltage (OCV) measurements across terminals of the battery when no load is being driven by the battery during the measurement phase, the first and second OCV measurements being taken at first and second charge levels, respectively; predicting a minimum open circuit voltage (OCV) corresponding to a
35 minimum charge level of the battery on the basis of the first and second OCV

measurements; and determining a current capacity and/or a capacity loss of the battery on the basis of the first and second OCV measurements and the minimum OCV.

- 5 The method may include controlling at least one vehicle sub-system (e.g. a vehicle regenerative braking system) on the basis of the current capacity or capacity loss of the battery.

10 For example, the method may comprise initiating a battery reconditioning cycle in the event that the current capacity drops below a predetermined threshold.

Alternatively, or in addition, the method may comprise providing a warning to replace the battery in the event that the current capacity drops below a predetermined threshold.

15 According to another aspect of the invention there is provided a vehicle provided with a battery monitoring system of the previous aspect of the invention.

20 The vehicle may be a conventional vehicle having only a combustion engine, a hybrid vehicle or a micro-hybrid vehicle.

According to a further aspect of the invention, there is provided a method of monitoring the capacity of a lead-acid vehicle battery using a processor and a measuring device, the lead-acid battery comprising an electrolyte of acid and water, the battery having a
25 charging phase during which a charge level of the battery is increased, a discharging phase during which the charge level of the battery is decreased and a measurement phase during which measurements are taken to determine the capacity. The method may comprise; measuring, using the measuring device, at least first and second open circuit voltage (OCV) measurements across terminals of the battery when no load is
30 being driven by the battery during the measurement phase, the first and second OCV measurements being taken at first and second charge levels, respectively; predicting, using the processor, a minimum open circuit voltage (OCV) corresponding to a minimum charge level of the battery on the basis of the first and second OCV measurements; and determining, using the processor, a current capacity and/or a

capacity loss of the battery on the basis of the first and second OCV measurements and the minimum OCV.

5 Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all
10 embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

15

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

20 Figure 1 is a top view of a vehicle having a battery with a battery monitoring system (BMS);

Figure 2 is an isometric view of the battery monitoring system (BMS) of an embodiment of the invention when connected to a vehicle battery;

25 Figure 3 is a system diagram showing the electrical connections between the battery monitoring system (BMS) and the vehicle battery in Figure 1;

30 Figure 4 is a flow chart showing the steps of a battery monitoring system algorithm of the battery monitoring system (BMS) in Figures 1 and 2;

Figure 5 is a graph showing the three open circuit voltage (OCV) measurements required by the battery monitoring system algorithm in Figure 3 to produce the battery monitoring algorithm output; and

Figure 6 is a graph showing the variation of the minimum slope, slope_{\min} , of the parameter dI/dt (where I is the current through the battery and t is time) with voltage and temperature.

5 DETAILED DESCRIPTION

Referring to Figures 1 to 3, a micro-hybrid vehicle 8 comprises a lead-acid battery 10 containing an electrolyte of acid and water and a battery monitoring system 12. The battery monitoring system 12 communicates with the main vehicle control system (not shown) which controls various vehicle systems and sub-systems, as is known in the art. This type of battery 10 is suitable for use in any vehicle type, for example traditional engine-driven vehicles, hybrid vehicles or micro-hybrid vehicle, but the invention lends itself in particular to micro-hybrid vehicles which incorporate an electric motor to start cranking of the engine and to supply electrical power to various functions in the vehicle 8. In such vehicles the battery is used repeatedly to re-start the engine after a temporary halt, and it is important to avoid situations where the battery has insufficient capacity to do so and renders the vehicle 8 stranded.

The battery monitoring system 12 comprises hardware 14 and software 16 components for collection and processing of data from the battery 10 for the purpose of monitoring the state of health (SoH) of the battery 10 when in use and without the need to take the vehicle 8 to a service station for checking. The hardware 14 comprises a microcontroller or processor, a measuring device in the form of a sensor for measurement of the battery current, I , a measuring device in the form of a sensor for measurement of the battery voltage, V , and a temperature sensor for measuring temperature. In practice the temperature sensor may be provided on the vehicle 8 in another location, with the temperature sensor output being provided to the processor of the battery monitoring system as well as to the main vehicle controller (not shown).

The battery monitoring system 12 is electrically connected to the battery 10 via a positive terminal 18, a negative terminal 20 and clamps 22, with a terminal interface 24 connected to ground through the vehicle body 26. The positive terminal 18 provides a sense signal to the battery monitoring hardware 14 via a connector 28, and a LIN

master module 30 communicates with the microcontroller through this same connector.

5 An object of the invention is to implement a method for determining battery capacity degradation using an algorithm 32 loaded onto a processor. Specifically, the algorithm 32 acts to quantify the storage capacity of the lead-acid battery which is lost due to sulfation. On the basis of this calculation an indication can be made of the remaining battery capacity i.e. the remaining concentration of battery acid.

10 A lead-acid battery cell is formed of a positive electrode (cathode) and negative electrode (anode) which are immersed in an electrolyte consisting of water and sulfuric acid. These cells are capable of storing 2V, such that a standard 12V battery for use in a vehicle consists of 6 cells connected in series. Sulfation is the process by which sulfate crystals form on the plates of a battery cell. This occurs each time the battery
15 10 is discharged, as sulfate crystals (PbSO_4) are a product of the discharge reaction. These sulfate crystals can be dissolved during the charging process, but the amount by which the crystals are dissolved depends on the solubility of the crystals, which decreases over time. If not all of the sulfate crystals can be dissolved, storage capacity of the battery 10 is lost as this locked material which is no longer in the electrolyte
20 solution is unavailable for the discharge reaction.

The inputs to the algorithm 32 loaded onto the microcontroller are the measured battery current, voltage and temperature as described previously. These inputs enable the sulfate crystal level in the battery cell 10 to be quantified, which enables the lost
25 storage capacity to be determined for use as a parameter to describe the State-of-Health (SoH) of the battery 10. To do this, the algorithm 32 uses measurements taken at first, second and third different charge levels and extrapolates measurements to the point of full battery discharge, but without the need to actually fully discharge the battery 10 to a dangerously low level. The algorithm 32 is designed for use with a
30 battery 10 when in a partial state of charge (PSoC), typically around 80% of full charge for the initial measurement and so battery monitoring can be undertaken during the regular use of the vehicle 8 and without removing the battery 10 from the vehicle 8 for testing. Measurements are typically taken within a window of 100-70% of the full charge state. Reference to "full charge" means the maximum charge that can be

achieved during operation of the battery in the vehicle, and not necessarily the maximum charge which could be achieved for the battery in laboratory conditions.

5 The ability to monitor the vehicle battery 10 in this way, with the battery 10 in situ in the vehicle 8 and the vehicle 8 in normal use, allows the measurements to be performed briefly and at convenient times.

10 In a charging mode (charging phase) for a micro-hybrid vehicle, the engine is running and the alternator is charging the battery 10. In a discharging mode (discharging phase) the battery 10 is losing charge either because it is being used to initiate starting of the engine or because electrical power is being supplied to a variety of vehicle functions, such as vehicle lighting or entertainment systems, the parking sensors etc. In a measurement phase during which measurements can be taken for the purpose of implementing the method of the invention, charging and discharging of the battery 10
15 is interrupted and the required measurements are carried out to determine the capacity of the battery 10. The measurement phase occurs between periods when electrical supply is required to the various vehicle functions and when re-start of the engine is not required following a temporary stop. By way of example, the measurement phase may occur when the vehicle is parked overnight.

20

The steps implemented in the algorithm 32 are described in detail with reference to Figures 4 and 5. Figure 4 is a flow chart showing the different steps undertaken by the algorithm 32 to determine the storage capacity lost due to sulfation.

25 In the first step 40 of the algorithm 32, the battery current, I , during a constant voltage charging phase is measured to determine if the battery 10 is fully charged (whatever the state of capacity of the battery). The rate of change of current with respect to time, dI/dt , indicates the charging rate of the battery 10. If $dI/dt \approx 0$, this means that the charging rate of the battery 10 is small, the dissolution rate of the sulfate crystals is small (as the sulfate crystals are dissolved during the charging process) and the
30 battery 10 is fully charged or close to being fully charged. The level below which the slope must fall (minimum slope 42) to indicate that the battery 10 is fully charged (and the algorithm 32 can move to the next step in the process) is dependent on the temperature and charging voltage of the battery 10. This relationship is illustrated in

Figure 6 which shows a pre-stored map indicating the minimum slope 42, slope_{\min} , as a function of voltage and temperature. For any set of voltage 43 and temperature 45 inputs to the map, the map provides an output, slope_{\min} 42, which represents the slope at which the battery is fully charged.

5

Once the current gradient value (dl/dt) falls below the minimum current slope level 42 for the appropriate voltage and temperature, the algorithm 32 moves on to a second step 44. In step 44 the charge, Ah, lost by the battery is monitored via measurement of the current as described in the following equation:

10

$$\text{Ah} = \sum I(n) * \Delta t \quad [1]$$

where Ah is charge in Ampere-hours, $I(n)$ is the battery current and Δt is change in time. This Ah-counter is used to observe the Ah-throughput and the state-of-charge change. Once the Ah-counter has determined that a certain amount of charge has been lost by the battery 10, denoted as ΔAh_1 46, and the battery 10 is in a new state of charge (SoC), the algorithm moves onto a third step 48.

20 In the third step 48, the open circuit voltage (OCV) is measured. The open circuit voltage is the voltage measured when no loads are being driven by the battery 10. This step must therefore be carried out during a measurement phase when the battery 10 is not in use, for example in the case when the vehicle is parked. The current in this case is known as the quiescent current, which is the current consumed when
25 substantially no loads are being driven and the measured voltage can be assumed with good approximation to be the OCV of the battery. Measurements of the OCV are taken using a measurement device connected across the terminals 18, 20 of the battery.

30 In this particular embodiment, the algorithm 32 obtains at least three OCV measurements at three different SoC levels. This is illustrated in the flow chart of Figure 4, where it is shown that the algorithm 32 does not progress to a fourth step 50 until at least first 52, second 54 and third 56 OCV measurements have been taken. If less than three OCV measurements have been taken, the algorithm 32 repeats the

second step 44 and the third step 48 until three OCV measurements have been obtained.

In theory it is possible for the method to be carried out with only two OCV
5 measurements, but accuracy is improved if three OCV measurements are obtained. A greater number of OCV measurements increases the accuracy still further.

During charging and discharging of the battery, the BMS 12 and main vehicle control
10 system are in communication with each other. When the sensors of the BMS 12 indicate that the battery 10 requires charging, the BMS 12 signals this information to the main vehicle control system. It is then the responsibility of the main vehicle control system to trigger charging of the vehicle battery 10 to full charge. At this point, the sensor determines the full charge state of the battery 10.

15 For measurement of the OCV values, the BMS sensor provides a trigger to the main vehicle control system for discharge and the main vehicle control system actuates discharge of the battery 10. The BMS sensor then records the OCV measurement at this discharge level and, after determination of measurement quality, sends another trigger to the main vehicle control system to continue the discharge procedure for
20 measurement of subsequent OCVs. For each of the OCV measurements, the BMS software 16 initiates a battery discharge event by signalling the main vehicle control system which in turn actuates discharging of the battery, so as to reduce the charge on the battery 10 to an appropriate level before the OCV measurement is taken. For example, the first level may be 80% of full charge, the second level may be 75% of full
25 charge and the third level may be 70% of full charge. Once the new charge level is reached, the relevant OCV measurement is taken and stored in a data memory of the microcontroller.

Figure 5 is a graph of battery OCV 60 (y-axis) versus capacity discharge 62 (x-axis)
30 showing first 52, second 54 and third 56 OCV measurements, $U_{ocv,1}$, $U_{ocv,2}$, and $U_{ocv,3}$, respectively, which are collected during the third step 48 of the algorithm 32 at three different states of charge respectively. The charge lost between the three OCV measurements is also shown, denoted as ΔAh_1 (46), ΔAh_2 (66), ΔAh_3 (68), where,

$$\Delta Ah_x = Ah(\text{at small charging current or } U_{ocv,x-1}) - Ah(U_{ocv,x}) \text{ for } x = 1 \dots 3 \quad [2]$$

The grey solid line 70 in Figure 5 shows the voltage obtained during a measurement phase of a capacity test, until reaching a defined minimum i.e. when the grey solid line reaches a defined minimum the capacity test is finished. The minimum OCV is the battery's OCV at the end of this capacity test.

On completion of the first 52, second 54 and third 56 OCV measurements, the algorithm 32 progresses to the fourth step 50 in which the molality of the acid in the battery 10 is determined. Molality (also referred to as molal concentration) is the measure of the concentration of a solute in a solution in terms of amount of substance in a specified amount of mass of the solvent. The fourth step 50 uses the well-known relationship between OCV and molality (which is temperature independent), wherein two different polynomial functions are valid depending on the value of $U_{ocv,x}$. For $U_{ocv,x} > 2V$, the following equation for molality is used:

$$\text{molality}(U_{ocv,x}) = U_{ocv,x}^2 * 25.138 \frac{\text{mol}}{\text{kg}} \frac{1}{V^2} - U_{ocv,x} * 75.354 \frac{\text{mol}}{\text{kg}} \frac{1}{V} + 52.776 \frac{\text{mol}}{\text{kg}} \quad [3]$$

20

and for $U_{ocv,x} < 2V$, the following equation for molality is used instead:

$$\text{molality}(U_{ocv,x}) = U_{ocv,x}^2 * 73.22 \frac{\text{mol}}{\text{kg}} \frac{1}{V^2} - U_{ocv,x} * 266.13 \frac{\text{mol}}{\text{kg}} \frac{1}{V} + 242.05 \frac{\text{mol}}{\text{kg}} \quad [4]$$

25

The molality is defined as the ratio between the amount of H_2SO_4 given in mol and the water mass given in kg,

$$\text{molality} = \frac{\text{amount } H_2SO_4}{\text{water mass}} \left[\frac{\text{mol}}{\text{kg}} \right] = f(U_{ocv}) \quad [5]$$

30

In a fifth step 72 of the algorithm 32, the absolute values of the water mass in kg and the amount of H_2SO_4 in mol are determined. It is known how the amount of H_2SO_4 and the amount of H_2O change during charging or discharging of the battery and this is described in the following set of equations,

35

$$\Delta \text{ amount H}_2\text{SO}_4[\text{mol}] = \frac{\Delta Q[\text{As}]}{\text{FaradayConst}[\text{As/mol}]} \quad [6]$$

$$\Delta \text{ amount H}_2\text{SO}_4[\text{mol}] = \Delta \text{ amount H}_2\text{O} [\text{mol}] \quad [7]$$

$$\Delta \text{water mass} = \Delta \text{ amount H}_2\text{O} * 18 \text{ g/mol} \quad [8]$$

5

where ΔQ is a defined change in charge and the Faraday constant, FaradayConst , is the magnitude of electric charge per mole of electrons and has a currently accepted value of 96485.3365(21) As/mol.

10

The absolute values of the water mass in kg and the amount of H_2SO_4 are determined using the following equation system:

$$\text{water mass}(U_{\text{ocv},1}) = \frac{\frac{\Delta \text{water mass}}{1000\text{g}} * \text{molality}(U_{\text{ocv},2}) + \Delta \text{ amount H}_2\text{O}}{\text{molality}(U_{\text{ocv},1}) - \text{molality}(U_{\text{ocv},2})} \text{ in kg} \quad [9]$$

15

$$\text{water mass}(U_{\text{ocv},2}) = \text{water mass}(U_{\text{ocv},1}) + \frac{\Delta \text{water mass}}{1000\text{g}} \text{ in kg} \quad [10]$$

$$\text{amount H}_2\text{SO}_4(U_{\text{ocv},x}) = \text{molality}(U_{\text{ocv},x}) * \text{water mass}(U_{\text{ocv},x}) \text{ in mol, with} \quad [11]$$

20

$$x = 1 \dots 3$$

Once the fifth step 72 has been completed, the water mass in kg and the amount of H_2SO_4 in mol is known at the three points of OCV measurement, such that the method can also be used to determine the water loss (assuming the amount of water is calculated for the same OCV value when the capacity method is used). In a sixth step 74 of the algorithm 32, the information gathered in the fifth step 72 regarding the amounts of water and H_2SO_4 at the three measurement points is used to extrapolate the OCV curve to the point which represents full battery discharge 76. In Figure 5 this extrapolated curve 78 is represented by the solid black line beginning at the final measured OCV value, $U_{\text{ocv},3}$ 56 and terminating at the point labelled 76. The point 76 at which this extrapolated line 78 terminates represents full battery discharge.

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In order to calculate the extrapolated OCV values 78, $U_{\text{ocv},x,\text{extrapolate}}$, which would be measured on discharge of a defined amount of capacity, $\Delta Q_{\text{dch,extrapolate}}$, it is first

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necessary to calculate the value of molality, $molality_{extrapolate}$, at the extrapolated lower state-of-charge points. This is done using the following equation:

[12]

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$$molality_{extrapolate}(\Delta Q_{dch,extrapolate}) = \frac{amountH_2SO_4(U_{ocv,3}) + \Delta amountH_2SO_4}{water\ mass(U_{ocv,3}) + \Delta water\ mass}$$

Using the relationship between OCV and molality, a polynomial approximation of the function $OCV = f(molality)$ is used to determine $U_{ocv,x,extrapolate}$ 78 based on $molality_{extrapolate}$. The polynomial functions used in this step are,

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$$U_{ocv}(molality) = molality^3 * 0.00005(V/(mol/kg)^3) - molality^2 * 0.0017(V/(mol/kg)^2) + molality * 0.0475(V/(mol/kg)) + 1.8863 V$$

[13]

15 which is valid for molality > 2.7mol/kg, and

$$U_{ocv}(molality) = molality^3 * 0.0105\left(\frac{V}{\left(\frac{mol}{kg}\right)^3}\right) - molality^2 * 0.0612\left(\frac{V}{\left(\frac{mol}{kg}\right)^2}\right) + molality * 0.161\left(\frac{V}{\frac{mol}{kg}}\right) + 1.8109V$$

[14]

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which is valid for molality < 2.7 mol/kg.

The calculation of new OCV values 78 is continued until the last calculated OCV value reaches a minimum 76 ($U_{ocv,min}$). At this point the real discharged capacity (ΔAh_1 64 to ΔAh_3 68), added to the assumed discharge capacity for the extrapolation of the OCV curve ($\sum \Delta Q_{dch,extrapolate}$) is taken to be the available capacity of the battery. The difference between the presently available capacity and the available capacity at the beginning of the battery lifetime is the capacity loss 80 in Ah:

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$$\Delta Ah_{loss} = Ah_{total,new} - \sum_{x=1}^3 \Delta Ah_x - \sum \Delta Q_{dch,extrapolate} \quad [15]$$

This calculation generates the output of the battery monitoring system algorithm 32 and completes the algorithm process 32. The output provides a direct measure of the

capacity loss 80, and so from this value the absolute capacity of the battery can also be determined.

For the described method to be performed, information is required regarding the initial available capacity in Ah (measured at 25°C and a discharge current for a 20 hour capacity test until the battery 10 has reached 10.5 V), the lowest possible OCV 76 ($U_{ocv,min}$), and the polynomial functions for molality = f(OCV) and OCV = f(molality). The polynomial functions for molality are stored on the memory of the processor. Furthermore it is required that occasionally the battery 10 is fully charged between the measurement phases of operation.

The three measurement points are taken over a period of time, typically a number of days. For example the first OCV measurement 52 may be taken overnight when the vehicle is parked, the second OCV measurement 54 may be taken on the subsequent night and the third OCV measurement 56 taken on the subsequent night again. Typically, measurements are spaced apart by at least 5-10 hours. In this respect, it will be appreciated that references to a 'measurement phase' include multiple separate time periods during which multiple measurements are taken, each of which is a separate time period from the usual operational phases of the battery. The method implemented by the algorithm 32 therefore operates over a relatively long timescale, but all steps of the method can be carried out when the vehicle is in normal use by the vehicle owner and does not require garaging or a vehicle service to be scheduled.

The initial OCV measurement 52 is typically taken when the battery 10 is discharged to around 80 percent of its full charge level. Discharging of the battery 10 to the lower charge levels required for subsequent OCV measurements reduces the state of charge to below 80%, but does not reduce the charge level appreciably. Discharging the battery 10 to a dangerously low level, for example a level at which re-start of the engine may not be possible or at which electric power supply to the vehicle functions is disrupted, is therefore not necessary using the method of the invention.

Additional measurements may be made, based on which the extrapolation 78 can be carried out, with the minimum number of OCV measurements required to determine the capacity loss being two. In addition, the measurements may be made in the

reverse order, starting with a first OCV measurement at a relatively lower state of charge and with charging of the battery 10 being initiated to a higher state of charge for the second, third and any subsequent OCV measurements. Extrapolation of the OCV measurements to determine the measurement at a full state of discharge is then
5 carried out in the direction of discharging to determine the minimum OCV measurement in the same way as described previously.

Once an estimate of the capacity loss and/or the capacity has been made it is possible to modify the control of various vehicle electric functions to accommodate any high loss of capacity. For example, it may be preferable to modify the supply of power to
10 internal lighting in the cabin or to the entertainment system so as to preserve available battery capacity for engine re-start, until such time as a battery service can be carried out. In other embodiments a battery reconditioning cycle may be initiated in response to the current capacity of the battery dropping below a predetermined threshold, or a warning may be provided to replace the battery in the event that the battery capacity
15 drops to below a predetermined threshold. It may also be desirable to moderate energy recovery during regenerative braking in the event of a low capacity being determined.

Many modifications may be made to the above examples without departing from the scope of the present invention as defined in the accompanying claims.

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CLAIMS

1. A battery monitoring system for monitoring the capacity or capacity loss of a lead-acid vehicle battery comprising an electrolyte of acid and water, the battery having
5 a charging phase during which a charge level of the battery is increased, a discharging phase during which the charge level of the battery is decreased and a measurement phase during which measurements are taken to determine the current capacity and/or capacity loss of the battery , the battery monitoring system comprising;
- 10 a measurement device for measuring, during the measurement phase, at least first and second open circuit voltage (OCV) measurements across terminals of the battery when no load is being driven by the battery, the first and second OCV measurements being taken at first and second charge levels, respectively;
- 15 a processor configured to predict a minimum open circuit voltage (OCV) corresponding to a minimum charge level of the battery on the basis of the first and second OCV measurements and to determine the current capacity and/or capacity loss of the battery on the basis of the first and second OCV measurements and the
20 minimum OCV.
2. The system as claimed in claim 1, wherein the measurement device measures at least first, second and third open circuit voltage (OCV) measurements at first, second and third charge states respectively and wherein the processor is
25 configured to predict the minimum open circuit voltage on the basis of the first, second and third OCV measurements.
3. The system as claimed in claim 1 or claim 2, wherein the processor is configured to determine the capacity loss of the battery based on the current capacity of the
30 battery and a pre-determined initial capacity of the battery.
4. The system as claimed in any of claims 1 to 3, wherein the processor is configured to determine the concentration of the water and/or acid in the battery based on at

least the first and second OCV measurements in order to predict the minimum OCV.

- 5 5. The system as claimed in claim 4, wherein the processor is configured to predict the minimum OCV by extrapolation based on at least the first and second OCV measurements.
- 10 6. The system as claimed in claim 5, wherein the processor is configured to determine an extrapolated value of the molality of acid at the minimum charge level and to predict the minimum OCV by extrapolation based on the determined extrapolated value of the molality of acid.
- 15 7. The system as claimed in any of claims 1 to 6, wherein the processor is configured to measure the first OCV measurement at a first relatively low charge level and to measure the second OCV measurement at a second charge level higher than the first charge level.
- 20 8. The system as claimed in any of claims 1 to 6, wherein the processor is configured to measure the first OCV measurement at a first relatively high charge level and to measure the second OCV measurement at a second charge level lower than the first charge level.
- 25 9. The system as claimed in any of claims 1 to 8, wherein the first and second charge levels are at least 80% of a maximum charge level of the battery.
- 30 10. The system as claimed in any of claims 1 to 9, wherein the processor is configured to control at least one vehicle electrical function on the basis of the determined current capacity of the battery.
- 35 11. The system as claimed in any of claims 1 to 10, wherein the processor is configured to measure the first and second OCV measurements during two separate measurement phases when the vehicle is parked.
12. A method of monitoring the capacity of a lead-acid vehicle battery comprising an electrolyte of acid and water, the battery having a charging phase during which a

- charge level of the battery is increased, a discharging phase during which the charge level of the battery is decreased and a measurement phase during which measurements are taken to determine the capacity, the method comprising;
- 5 measuring at least first and second open circuit voltage (OCV) measurements across terminals of the battery when no load is being driven by the battery during the measurement phase, the first and second OCV measurements being taken at first and second charge levels, respectively;
- 10 predicting a minimum open circuit voltage (OCV) corresponding to a minimum charge level of the battery on the basis of the first and second OCV measurements; and
- determining a current capacity and / or a capacity loss of the battery on the basis of
- 15 the first and second OCV measurements and the minimum OCV.
13. The method as claimed in claim 12, comprising controlling at least one vehicle sub-system on the basis of the current capacity or capacity loss of the battery.
- 20 14. The method as claimed in claim 13, comprising initiating a battery reconditioning cycle in the event that the current capacity drops below a predetermined threshold.
15. The method as claimed in claim 13 or claim 14, comprising providing a warning to replace the battery in the event that the current capacity drops below a
- 25 predetermined threshold.
16. The method as claimed in any of claims 12 to 15, wherein the at least one vehicle sub-system includes a vehicle regenerative braking system.
- 30
17. A vehicle comprising a battery monitoring system as claimed in any of claims 1 to 11.
18. The vehicle as claimed in claim 17, wherein the vehicle is one of a combustion-
- 35 engine driven vehicle, a hybrid vehicle or a micro-hybrid vehicle.

19. A method substantially as herein described with reference to the accompany drawings.

5 20. A battery monitoring system substantially as described herein with reference to the accompanying drawings.

21. A vehicle substantially as described herein with reference to the accompanying drawings.

10

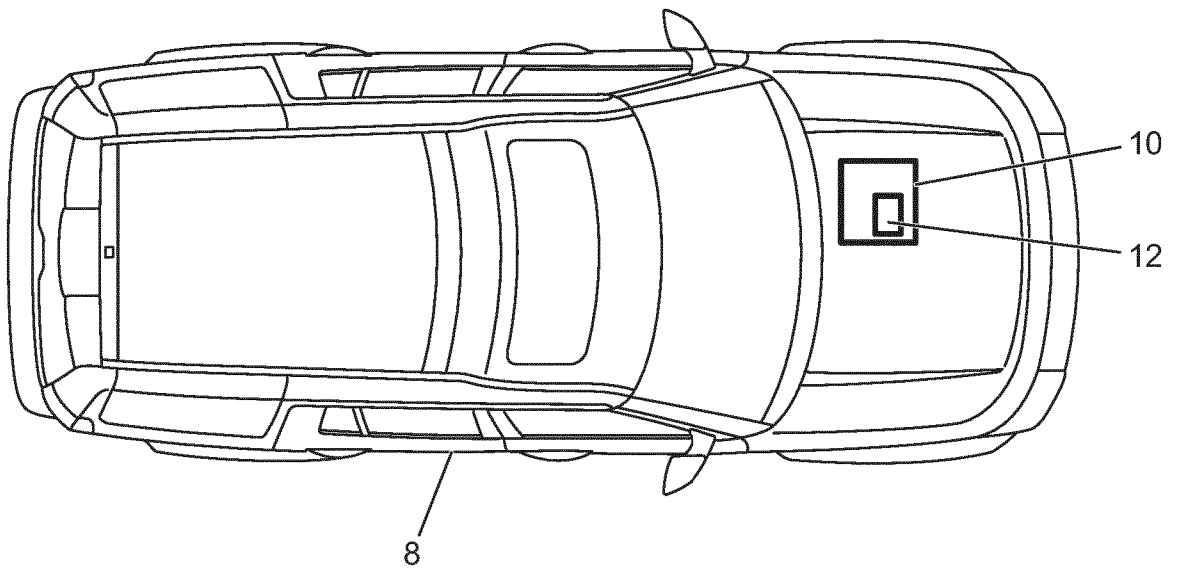


Fig. 1

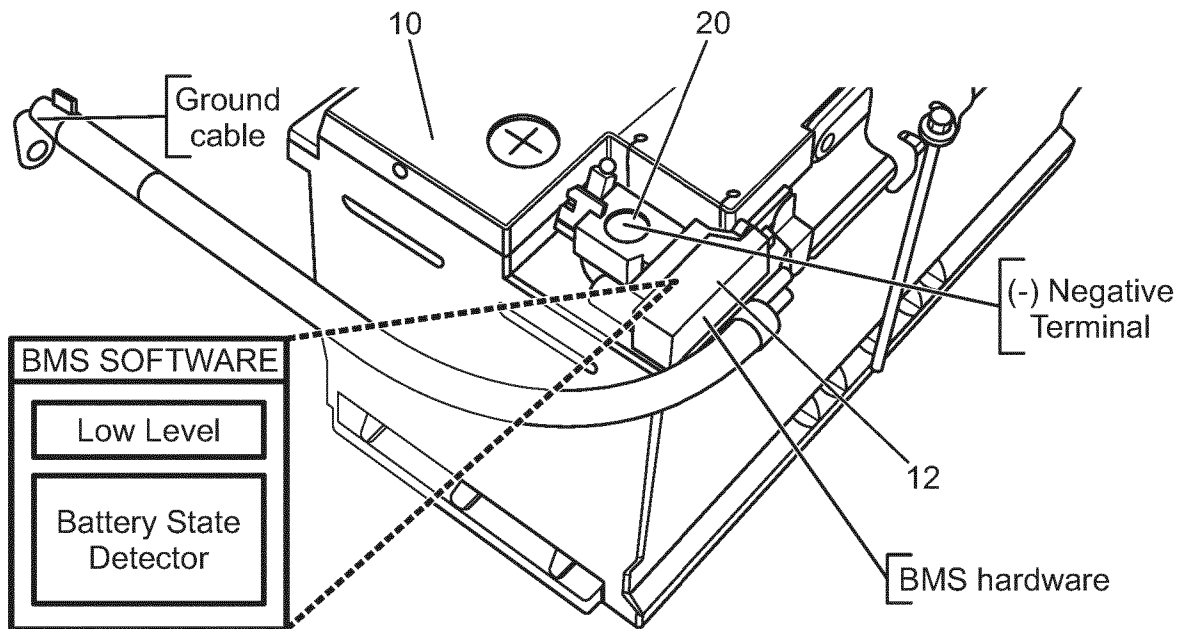


Fig. 2

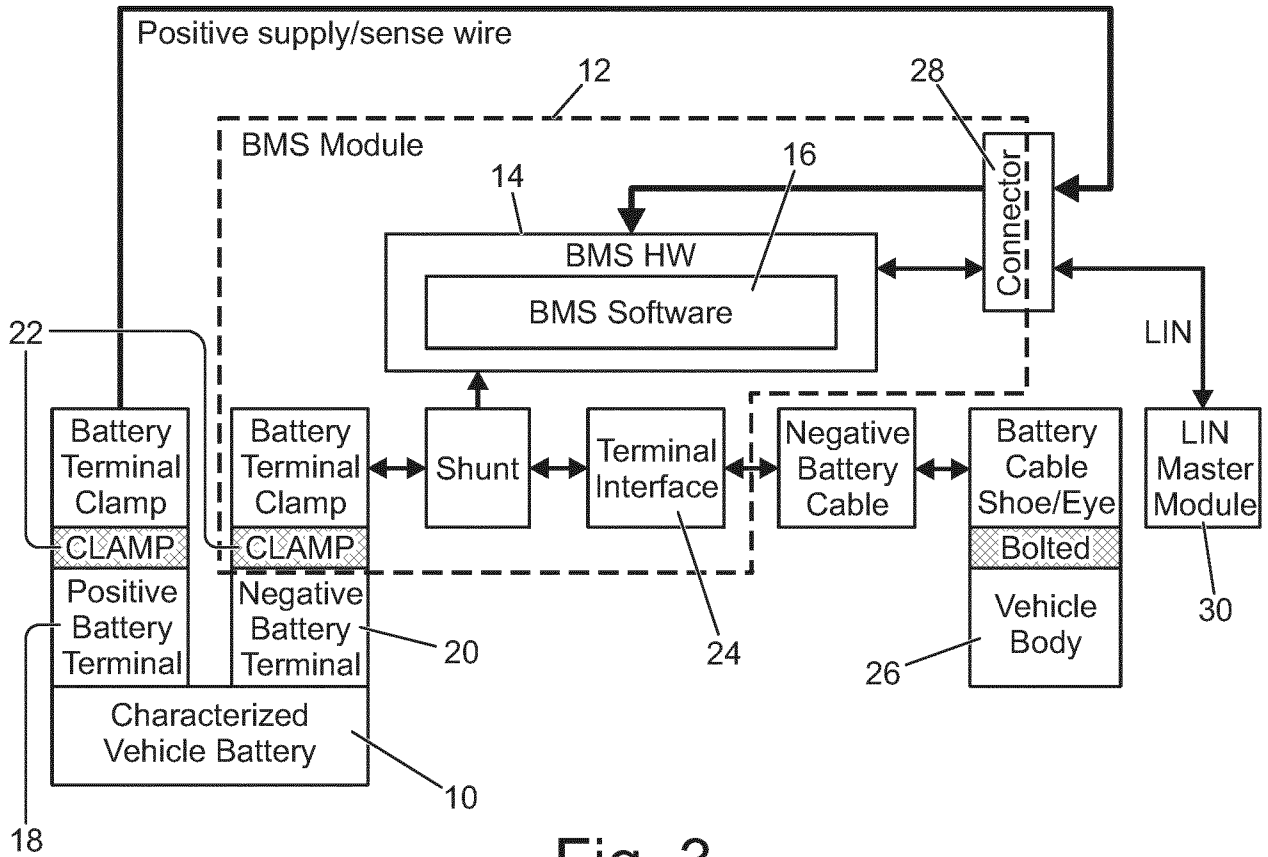


Fig. 3

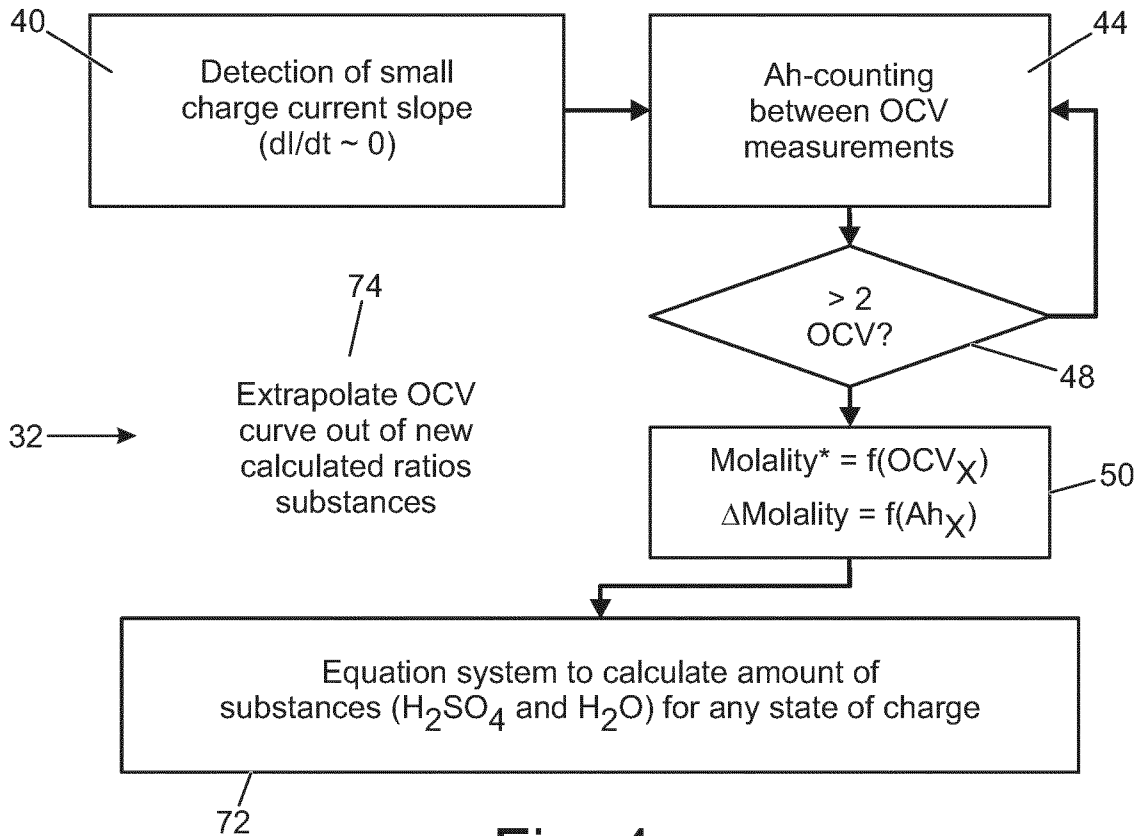


Fig. 4

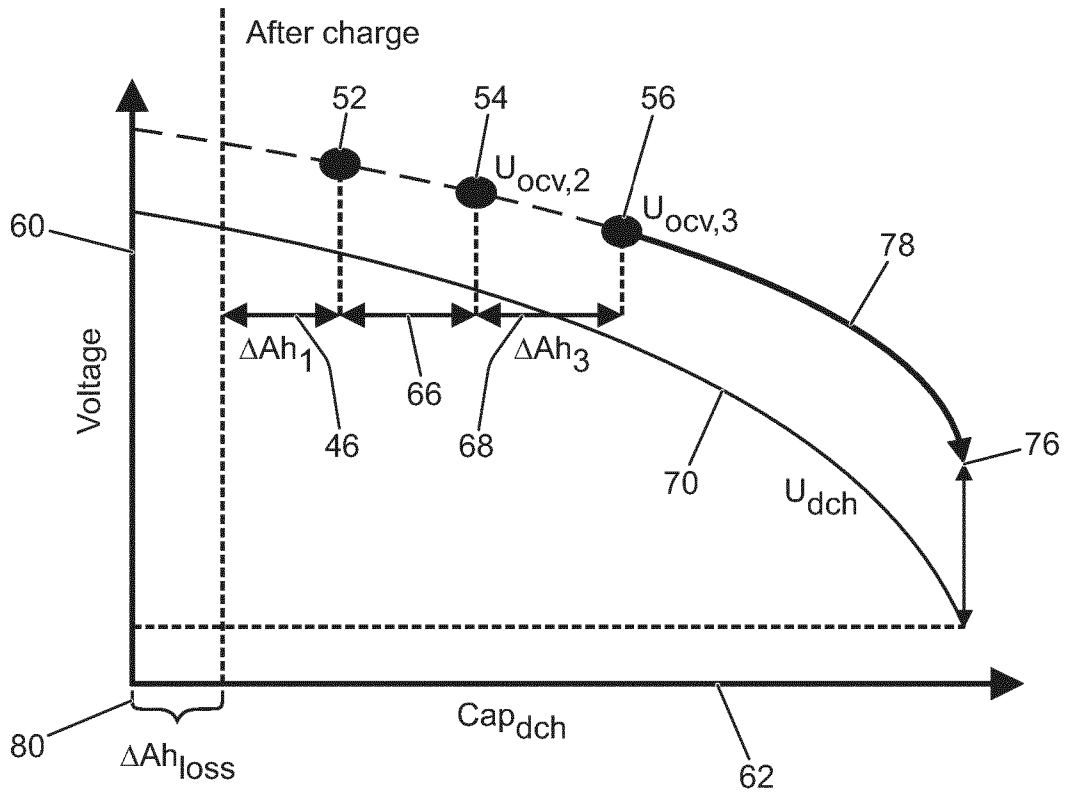


Fig. 5

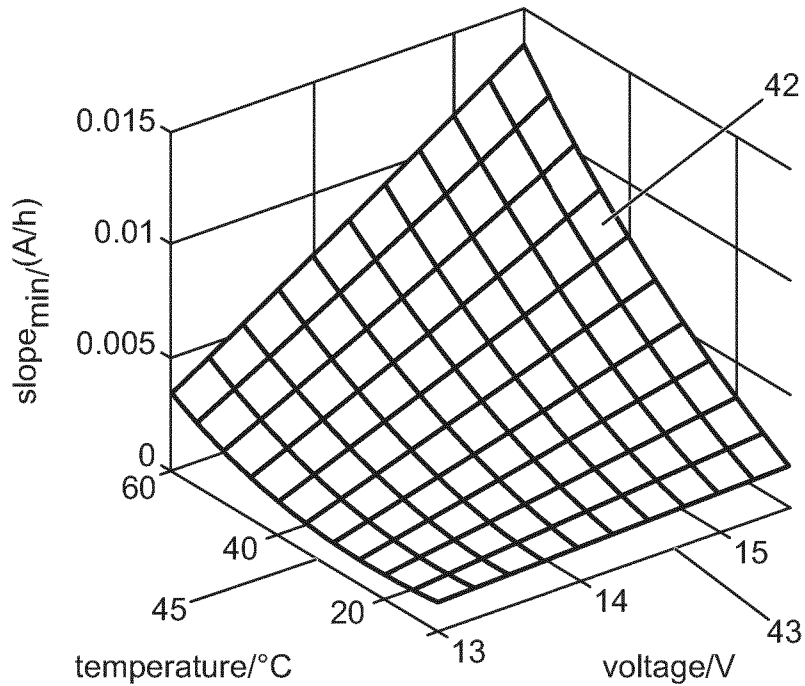


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/069725

A. CLASSIFICATION OF SUBJECT MATTER INV. G01R31/36 ADD.		
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) G01R		
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 practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 962 099 A2 (DELPHI TECH INC [US]) 27 August 2008 (2008-08-27)	1-5,7-21
A	paragraphs [0014] - [0032]; claims 1-8; figures 1-2	6

X	US 6 366 054 B1 (HOENIG STEVEN [US] ET AL) 2 April 2002 (2002-04-02)	1-5,7-21
A	column 1, lines 6-66; claims 1-11; figures 1-4 column 3, line 8 - column 9, line 23	6

A	WO 2006/054066 A1 (TRW LTD [GB]; TUCKER MARK RICHARD [GB]; WAKEMAN ANTHONY CLAUDE [GB]) 26 May 2006 (2006-05-26) the whole document	1-21

<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	
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"P" document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search	Date of mailing of the international search report	
24 October 2016	03/11/2016	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Bilzer, Claus	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/069725

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 1962099	A2	27-08-2008	
		CN 101251582 A	27-08-2008
		EP 1962099 A2	27-08-2008
		KR 20080077572 A	25-08-2008
		US 2008197807 A1	21-08-2008

US 6366054	B1	02-04-2002	
		CA 2446240 A1	14-11-2002
		EP 1384086 A1	28-01-2004
		JP 4132036 B2	13-08-2008
		JP 2004530880 A	07-10-2004
		KR 20040015242 A	18-02-2004
		US 6366054 B1	02-04-2002
		WO 02091007 A1	14-11-2002

WO 2006054066	A1	26-05-2006	NONE
