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TECHNICAL REPORT

Guidelines for the use of monitor systems for lead-acid traction batteries

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INTERNATIONAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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IEC TR 61431, which is a Technical Report, has been prepared by IEC technical committee 21: Secondary cells and batteries.

This second edition cancels and replaces the first edition, published in 1995. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) The guidelines have been streamlined in terms of technical content and focussed for automatic monitoring systems.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
21/1044/DTR	21/1053A/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

GUIDELINES FOR THE USE OF MONITOR SYSTEMS FOR LEAD-ACID TRACTION BATTERIES

1 Scope

This document is an informative document relating to aspects of automatic monitor systems as utilized in lead-acid traction battery applications. It lists the characteristics and features that need to be monitored and evaluated to properly assess the operative status of a traction battery. Guidance concerning the accuracy and reliability of the generated information is also provided.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Desirable characteristics and features

4.1 General

This Clause 4 lists relevant characteristics and features, which, if measured or implemented, would contribute information towards the assessment of the operational condition of a lead acid traction battery. The characteristics are not listed in any order of priority.

The battery monitor system (BMOS) described in this document is a device solely collecting and reporting data and should not be confused with a battery management system (BMS) actively controlling the battery.

4.2 Physical location of the monitoring device

The device may be installed in one of the following locations:

a) directly on the battery,

b) on the charger,

c) on the vehicle.

Location a) is the preferred option as it provides continuous and continued monitoring. Option b) and c) require additional methods to properly identify which battery is currently being monitored. This requires a unique battery ID to be made available for battery recognition. Such an ID could be stored for example on an RFID tag, a 2D QR code, NFC device or similar information depositories.

If the device is directly integrated into the battery, the unique battery ID can be stored in the device itself and the above-mentioned methods of battery identification are not needed.

4.3 State of charge indication or "fuel gauge"

The precise knowledge of the state of charge or driving range capability is a key functionality of a monitor system. The device should allow these values to be displayed in a fuel gauge manner with an acceptable error tolerance and without the necessity to undertake a capacity test. Low state of charge or driving range should be indicated by an alarm signal.

4.4 Battery temperature information

Battery temperature is a crucial measuring parameter. The location of the temperature probe should be selected so as to measure the electrolyte temperature of the hottest cell of the battery.

When the battery is powering equipment operated for example in cold storage warehouses, the probe should be preferably located at the coolest cell of the battery.

The actual value and its integration over service time are essential to predict discharge capacities, adjust recharge conditions and predict battery lifetime.

4.5 High battery temperature warning

Temperatures in excess of 60 °C over a period of several hours can cause rapid degradation of the battery. In batteries with valve regulated cells, such temperature levels may cause a thermal runaway within a few hours leading to copious gas evolution and ultimate destruction of the cells. A specific high temperature warning signal should be generated by the monitor system to alert the operator.

4.6 Low temperature warning

Storage temperatures below −5 °C may cause electrolyte freezing in a discharged battery. The monitor system should generate an adequate warning signal for information purposes only.

4.7 Electrolyte level indication

In vented cells the correct filling level of the electrolyte is crucial to achieve service life. This requires a periodic topping up of the electrolyte level with deionized or distilled water. The actual electrolyte level is generally displayed visually on each cell with a floating device integrated in the vent or watering plug. The electrolyte level of a selected cell, i.e. the pilot cell, can be also transmitted via appropriate electrical circuits to the monitor system. Low electrolyte levels should trigger a warning signal calling for inspection and, if confirmed, for addition of water. It is however recommended that an additional visual inspection be carried out periodically as floating level sensors may get stuck, erroneously indicating an adequate filling level or causing an overfilling.

4.8 Electrolyte level maintenance log

The frequency of water additions and quantities needed increase as the vented battery ages. Operating conditions and/or latent defects may further increase the need for maintenance. The date of electrolyte level adjustments and, if accessible, the quantity of re-filled water should therefore be recorded in a maintenance records section of the monitor system. This is of particular relevance if an automatic watering system controlled by the charger is used. This generally requires the monitoring system to be located in the charger or to be able to communicate with the charger.

4.9 Uniformity of cell properties in a battery

A traction battery is an assembly of multiple 2 V single cells or 4 V, 6 V, or 12 V monoblocs. The status of each individual cell contributes to the energy delivery capability, charge acceptance and service life expectancy of the battery itself. Ideally the voltage of each cell of the battery should be monitored continuously to detect present or developing anomalies. These voltages should be measured and recorded, for example, at 1 min intervals and with a 10 mV resolution and displayed in such a way that absolute voltage levels, or the deviation from the average cell voltage are displayed in a colour graduated way (green to orange to red to blinking red) according to defined deviations or absolute values. This display should replicate the layout of the cells in the battery so that the operator can by guided properly to carry out further inspections or correlate cell property values with the location of local heat sources, loose connectors, etc.

4.10 Battery commissioning date

In order to properly correlate and gauge the monitored battery characteristics and features, the date of first use or commissioning should be made available to the monitor system and embedded in the most appropriate way in the battery identification tag as per 4.2.

4.11 Battery configuration

In this document, and in particular in 5.4, it is assumed that the battery is configured by connecting cells, monoblocs and batteries in series only and not in parallel.

5 Evaluation and analysis

5.1 State of charge indication or "fuel gauge"

The state of charge or SoC of a battery refers to the number of ampere hours discharged in relation to a reference capacity value. This reference value may be the 5-hour rated capacity value as declared by the manufacturer. However, this calculated value represents only a simple "ampere hour" accounting-based state-of-charge (SoC) value, i.e.

$$Q_{est} = C_N - Q_{dis} \text{ (Ah)}$$

where

Q_{est} is the capacity estimated to be available for further discharge expressed in ampere hours;

C_N is the rated capacity expressed in ampere hours;

Q_{dis} is the capacity discharged expressed in ampere hours.

This is a very simplified approach as the actual battery capacity may no longer relate to the rated capacity value due to insufficient charging, ageing, temperature and discharge current level effects.

Summing up the discharged ampere hours and subtracting them from an assumed arbitrary 100 % state of charge at the beginning of the charging procedure can yield an ad-hoc state of charge indication. Such a calculation needs in any case to take into account the ampere hours recharged during possible opportunity charging or braking energy recovery.

A more precise indication of the state of charge of a lead-acid battery or expected autonomy time or remaining driving range of the vehicle should consider multiple impacts of the actual discharge parameters and conditions on the effective available battery capacity.

5.2 Battery temperature information

The temperature of the electrolyte in the cell has a major impact on cell capacity and life.

Increased battery temperatures accelerate ageing. The battery lifetime is diminished by 50 % for every 10 °C above the rated 30 °C reference temperature.

For proper operation, any traction battery assembly in steel trays or similar should ensure a homogenous cell temperature with the temperature difference between the hottest and coldest cell not exceeding 3 °C. If the battery is split into two or more separate trays on the vehicle, then additional attention should be given to suitable probe location and temperature homogeneity.

The location of the temperature probe should be chosen appropriately to reflect either the average electrolyte or cell or battery temperature with a preference towards locations where higher than average temperatures are present.

The probe can be inserted into the electrolyte or between the walls of two adjacent cells or monoblocs. The probe may also be attached to the lead part of a terminal. However, the value found should represent the internal cell or electrolyte temperature and not localized hot spots due to ohmic heating caused by loose or undersized connectors.

Adequate corrosion protection of the probe and connecting leads is mandatory.

In addition to the temperature at the probe location, the temporal distribution of the temperature should be also recorded.

In Table 1 the variables t_1 through t_5 can be used to accumulate residence times of the battery at different temperature levels. Warnings and alert should be sent when the temperature exceeds the warning levels listed in Table 2.

For this purpose, the actual time, preferably in minutes, during which the temperature of the battery was within a certain range should be documented in conjunction with the unique ID number of the battery, if applicable.

Table 1 – Residence times and related temperature ranges

Duration within the selected temperature range	Temperature range for vented cells °C	Temperature range for valve-regulated cells °C
t_1	< 10	< 10
t_2	10 to 40	10 to 30
t_3	40 to 50	30 to 40
t_4	50 to 55	40 to 45
t_5	> 55	> 45

Table 2 – Temperature warning levels

Action	Temperature range for vented cells °C	Temperature range for valve-regulated cells °C
Send warning	≥ 55	≥ 45
Send high temperature alert	≥ 60	≥ 55

5.3 Water consumption

Vented cells require a periodic adjustment of the electrolyte level with addition of distilled or deionized water according to the specific, cell-design related manufacturer's instructions.

The electrolyte level can be monitored remotely in a pilot cell with an output signal routed to the monitor system indicating, "*level OK*" or "*level too low*". This warning signal should induce the operator to verify the correctness of the warning and, if confirmed, to carry out the level adjustment with a manual or automatic watering system. The warning signal may be delayed as the electrolyte level varies with the state of charge and with the tilt angle of the battery (i.e. vehicle on an incline).

At the conclusion of this level adjustment, the operator should be required to delete the warning signal from the display of the monitor system.

The date and time of the appearance of the signal "*level too low*" and its deletion by the operator should be recorded and tied to the unique ID number of the battery, if applicable.

The interval between level adjustments and the promptness of carrying such maintenance operation can then be reconstructed, as desired, from the time stamps stored in the monitor system.

5.4 Uniformity of cell properties

The uniformity of the performance of the cells in a battery is key to achieving long service life. Any data acquired needs to be unambiguously tied to a unique ID number of the battery, if applicable.

Monitor systems should acquire the following voltages at 1 min intervals with 10 mV resolution during charge, discharge and in stand-by:

1) all individual cell voltages; or
2) all individual monobloc voltages; or
3) the voltage of each half of the battery string; or
4) combined voltage levels of equal numbers of cells connected in series but not combining more than 6 cells for each monitored voltage level.

The guiding principle of the granularity when monitoring cell properties, should be the best compromise between the number of sensing cables and associated contacts, the data logging and data storage capability of the monitoring device and the achievable responsiveness of the algorithms of the monitor system designed to detect incipient degradations in battery performance.

These voltage values should be time-stamped and therefore facilitate correlation with the magnitude, and direction of the current flowing through the battery and the associated battery temperature. This would also allow the establishing of a usage pattern of the battery involved.

5.5 Electrolyte density

The electrolyte of the lead-acid battery participates in electrochemical reactions during charging and discharging of the battery. The sulphuric acid concentration, or in good approximation, the electrolyte density changes with the state of charge of the battery.

It is customary that the concentration of the electrolyte is reported as density expressed in g ml^{-1} at the reference temperature of 30 °C.

Trained operators are thus capable, for example, of verifying the completion of battery charging and of cell status by measuring manually the electrolyte density with a suitable hydrometer.

No reliable devices are currently available which, when installed in a cell, could measure and report the proper density value to the monitor system as an electrical signal.

Nevertheless, an empirical correlation between the observed cell voltage and the density is given by the equation

$$\rho_{El} = U_{oc} - 0{,}840 \text{ (between 15 °C and 35 °C)}$$

where

ρ_{El} is the electrolyte density expressed in g ml^{-1};

U_{oc} is the open circuit voltage of the cell expressed in V.

In order to obtain appropriate density values, several hours on standby in open circuit are required. Therefore the use of this empirical correlation is not a suitable way for a timely display of the electrolyte density by the monitor system.

5.6 Capacity throughput

Any discharge of the battery causes a small irreversible degradation of the cell structures involved in the storage and delivery of energy from the battery.

The total amount of capacity or energy that can be discharged from a battery over its life is generally defined as the capacity throughput capability, i.e., the product of rated battery capacity with the number of complete discharges or cycles to a defined final voltage at 30 °C.

Very shallow or very deep discharges alter this throughput capability value as also discussed in Annex A.

Several throughput summaries should be generated. It is essential that these summaries be tied to the unique ID number of the concerned battery, if applicable:

– ΣQ_1 accumulated total of ampere hours discharged where discharge is defined by the direction of a current flow from the battery;

– ΣQ_2 accumulated total of ampere hours charged where charge is defined by the direction of a current flow into the battery.

If desirable, also the energy throughput could be summed and stored in the monitor system such as:

– ΣE_1 accumulated total of watt-hours discharged where discharge is defined by the direction of a current flow from the battery;

– ΣE_2 accumulated total of watt-hours charged where charge is defined by the direction of a current flow into the battery.

5.7 Battery age

Certain battery properties recorded or calculated by the monitor system should be assessed in relation to the number of elapsed days since battery commissioning. This date should be properly defined, tied to the unique ID number of the concerned battery and made available to the monitor system by appropriate means such as a RFID tag, QR 2D barcode, NFC device or similar if applicable.

5.8 Battery data sheet

It is essential that a complete and binding set of performance data and operating characteristics of the concerned battery, are present and available for automatic interrogation by the monitor system.

These data could be conveniently stored on RFID tags, QR 2D barcodes or similar devices.

The data should comprise for example:

- date of commissioning the battery;
- rated capacity C_5 at the 5 h rate to 1,70 V per cell at 30 °C;
- rated Ah throughput capability over battery life in multiples of 5-hour capacity;
- temperature limits on discharge and charge;
- current, voltage and time limits when on charge and discharge;
- recommended charge profile(s);
- battery weight and manufacturer;
- rated electrolyte density at 30 °C when applicable (vented cell design).

5.9 Communication interfaces

The monitor system should provide visual information (warning lamps and indicators) for reassuring or alerting the operator.

The battery monitoring system should be able to communicate wirelessly to access the collected data. Alternatively, it should be able to upload the data to a cloud based system, from where it can be accessed. The .csv or comma-separated value file format is recommended for data storage and exchange. This file format can be readily read and data analysed with spread sheet software.

The monitoring system should preferably also be able to communicate with chargers and/or vehicles. The communication methods can include WWAN, WLAN, WPAN, Bluetooth or CAN-bus standards.

The interaction of the monitor system with the operator and battery system should ensure that no potentially dangerous situations (e.g. excessive temperatures) are allowed to develop but also ensure that the battery monitoring system does not induce disruptive stoppage of vehicle operation or movement. It is preferable to impair the battery rather than to stop vehicle movement in the middle of a lifting task, road intersection or railway track.

5.10 Ground faults

Spillage of battery electrolyte on the surface of the cells may generate conductive paths to earth ground. Such paths may cause ground fault currents to flow and the associated arcing may ignite the battery.

The monitor system could incorporate a ground fault monitoring function to monitor the insulation resistance between the battery and the frame of the vehicle.

The recommended insulation resistance is:

for batteries in service: ≥ 50 Ω/V with a minimum of 1 000 Ω per battery;

for new batteries: ≥ 1 MΩ.

More stringent requirements for insulation resistance may exist in certain regions or for certain applications and these take precedence.

5.11 Human factors

The monitoring device provides proper information and guidance for achieving a long battery service life.

Its data logging and warning functions can also reveal abuses that could expose the operator to labour sanctions, void battery warranties or hide manufacturing defects in the battery.

It will therefore be necessary that safeguards are built into the monitor system preventing deliberate data losses or deletions as well as bypassing protective features.

6 Data monitoring – Recommended list of parameters to be monitored

A list of recommended battery parameters, either measured directly or calculated by the monitoring system, is shown in Table 3. The desirable resolution of the values made available to the battery operator is also listed.

Table 3 – Units and value resolution of measured characteristics

Characteristics	Units	Resolution of the available data
Time	Minutes	1
Temperature log	°C	1
Average battery temperature	°C	1
Maximum observed battery temperature	°C	1
Minimum observed battery temperature	°C	1
Cumulated residence time at each of the temperature ranges t_1 to t_5 as per Table 1	Minutes	10
Battery voltage log	V	0,1
Cumulated time the on-load battery voltage has been below a voltage defined as deep discharge voltage or at a SoC value below the permitted minimum as declared by the manufacturer	Minutes	1
Single cell or monobloc voltage log	V	0,01
Discharge current log	A	1
Charge current log	A	1
Ah discharged since the last charge	Ah	0,1
Ah charged since the last discharge	Ah	0,1
Cumulated time on discharge	Minutes	1
Cumulated Ah discharged since battery commission	Ah	1
Cumulated Ah discharged expressed as equivalent rated capacities	No.	0,1
Cumulated time on charge	Minutes	1
Cumulated Ah charged since battery commission	Ah	1
Number of discharge events lasting longer than 5 minutes	No.	1
Number of charge events lasting longer than 5 minutes	No.	1
Cumulated time on open circuit i.e. with current flow level < 0,5 A	Minutes	10
Cumulated kWh discharged since battery commission	kWh	1
Cumulated kWh charged since battery commission	kWh	1
Interval between activation of a warning signal and completion of corrective action	Minutes	10
Electrolyte level adjustment warnings	No.	1
Log of the time interval between electrolyte adjustment warnings and completed corrective action	Minutes	10

The above list is for guidance only and multiple additional data combinations could be generated so as to further characterize the actual status and remaining service life reserve of a traction battery.

7 Analysis and evaluation of gathered battery data

7.1 Data flow

A possible flow of data in a monitor system is shown in Figure 1.

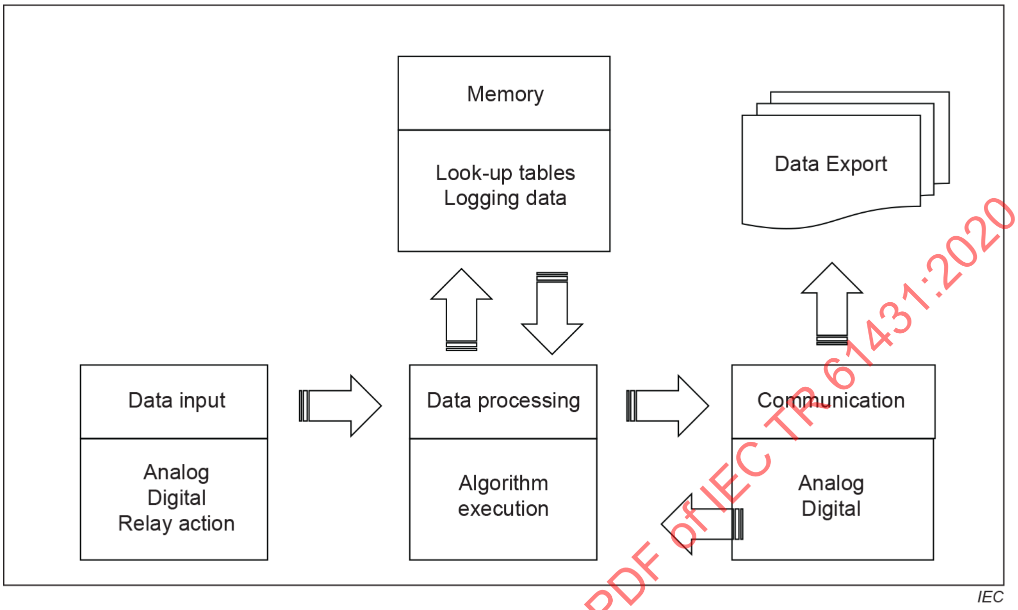

Figure 1 – Potential data flow in a monitor system

7.2 Prediction of residual operational life

The residual operational life can be expressed as leftover or residual ampere hour throughput capability ΣQ_{R1}.

This simplified approach assumes that the battery will be operated in the future under the conditions for which the cycle life or ampere hour throughput capability has been warranted by the manufacturer.

The residual ampere hour throughput capability is obtained as the difference between the manufacturer's warranted total capacity throughput capability ΣQ_{R1} and the sum of ampere hours already discharged ΣQ_{D1}

$$\Sigma Q_{R1} = \Sigma Q_1 - \Sigma Q_{D1}$$

The value ΣQ_{D1} should integrate correction factors that take into consideration the past operational history of the battery in terms of operating conditions.

A method of calculating the residual operational life of a battery is given as an example in Annex A.

Annex A
(informative)

Example determination of the residual service life of lead-acid traction batteries

A.1 General

In the following a model calculation of the residual capacity throughput and service life capability of a traction battery is given. Based on the manufacturer's warranted total capacity throughput capability $\sum Q_1$ the residual operational life can be calculated. The remaining capacity throughput is then determined by subtracting the sum of already discharged capacity $\sum Q_{D1}$ and the lost capacity throughput due to additional degradation stresses originating from non-ideal operating conditions.

No generally applicable list of stress factors for the degradation is available. Stress factors used in the relative formulas and the resulting degree of degradation shown in the examples, are based on generic industry experience and should be considered to have informative value only. Specific values should be requested from the manufacturer.

A.2 Lost capacity due to stress factors

A.2.1 Evaluation of the impact of a deep discharge

Deep discharge will reduce the battery lifetime. The battery is in deep discharge condition when one or more of the following conditions a), b) or c) are met:

a) when more than 80 % (vented cell design) or 60 % to 80 % (VRLA cell design, depending on manufacturer and battery size) of the rated C_5 capacity has been discharged/used;

b) when during discharge a voltage value below that represented by the continuous line on Figure A.1 has been recorded for more than 1 min;

c) when during storage, the cell voltage has fallen below the open-circuit voltage

$$U_{oc} = 0{,}84 + d_{min}$$

For vented batteries d_{min} is the density of the electrolyte at 80 % depth (C_5) of discharge at 30 °C expressed in kg/l.

For VRLA batteries the value U_{OC} is the voltage value declared by the manufacturer.

Each of the conditions a), b), and c) generate a time value which is accumulated in the same counter according to Table 3, row number 8.

The time in deep discharge condition reduces the residual capacity throughput capability according to

$$Q_{D2} = \sum \left(Q_1 \frac{t_{deep}}{60} \frac{1}{24} \frac{1}{30} \frac{5}{100} \right)$$