Operation Manual
for 2V ZeMa Cells

Concern: **Operation Manual for Rolling Stock VRLA TPPL+Sn Single cells: ZeMa200P18, ZeMa270P12, ZeMa340P12 and ZeMa450P21**

Author: Gordon Babock
Global Product Manager MP Specialties

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Rail Engineering
Dieckstrasse 42
DE-58089 Hagen

Tel. +49 (0) 2331/372 591
Fax +49 (0) 2331/372 804

www.enersys.com

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1. About this document

1.1 General Information

This document provides instructions and technical information for the operation and service of rolling stock single cell batteries in Railway applications. It covers the product range of 2V ZeMa*Rail* single cells with VRLA (AGM), TPPL+Sn Technology:

- ZeMa200P18
- ZeMa270P12
- ZeMa340P12
- ZeMa450P21

DO NOT commence operating or working on the battery until the “EMEA 2VZeMa Rail Cells Operation Manual” instructions have been carefully read. Please file the documents for future consultation. Additionally please study the technical documents about your battery system and your application.
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Paying close attention to these instructions will avoid possible hazards that can be caused by batteries, it will also reduce future repair and/or down time and will help increase the service life of the battery. Ignoring the operating instructions and repairing batteries with non-original parts will void the battery warranty. All failures, malfunctions or faults of the battery, the charger or any other accessories, must be notified to our After Sales Service immediately.

1.2 Definitions and Abbreviations

AGM	Absorbent Glass Mat
PbSn	Lead tin (Alloy)
BMS	Battery Monitoring System
DOD	Depth of Discharge
NTC	Negative Temperature Coefficient
OCV	Open Circuit Voltage
TPPL	Thin Plate Pure Lead (EnerSys Technology)
TPPL+Sn	Thin Plate Pure Lead with PbSn (EnerSys Technology)
SOC	State of charge
Vpc	Volt per cell
VRLA	Valve Regulated Lead Acid (battery)
V-0	Fire protection classification acc. UL-94 or EN 60695-11-10 (EnerSys uses V0 in type designation)
ZeMa	Zero Maintenance

1.3 Reference documents

❑	EN 62485-2 : 2019 EN 62485-3 : 2015	«Safety requirements for secondary batteries and battery installations» (European Standard) Part 2 : Stationary batteries Part 3 : Traction batteries
❑	EN 60077-1 : 2018	«Railway applications - Electrical equipment for rolling stock» Part 1 : General service conditions and general rules
❑	EN 50547 : 2013	«Railway applications – Batteries for auxiliary power supply systems»
❑	Leaflet	Information for the Safe Handling of Lead-Acid Batteries (EnerSys, Dec_2016)

2. Safety

2.1 General Safety information

Operation manual, nameplate and warning signs etc. must always be kept at the plant site and if possible made clearly visible in the battery compartment.
In principle, the internal instructions of the railway companies shall apply.
A full list of warning & information sign is listed in chapter 16 Appendix 7.

Follow instructions

Operation manual must be handed over to the competent personnel.
A copy shall be available at the **charging location**.

Work on batteries only after instruction by qualified personnel.

First aid

If any Acid splashes into eyes or onto skin **rinse under clear running water**. After contact with eyes seek immediate advice from a **medical doctor**, please also contact your doctor after serious skin contact.
If Electrolyte Splashes reach the eyes,
Clothing contaminated by acid should be washed with water and soap.

Pay attention to the hazards that can be caused by batteries.

Pay attention to the dangers posed by batteries like **stored energy, short circuit, DC current, explosive gases and electrolyte leakage**.

Dangerous electrical voltage !

All **exposed metal parts** of the battery cells are permanently live. Danger of injury by electric shock.

Touch the battery only on the plastic surfaces.

Electrolyte is highly corrosive !

If Electrolyte Splashes reach the eyes, immediately wash the eyes with **plenty of clean water**. In case of accident consult a doctor immediately!

In normal operation, a contact with the electrolyte is excluded. At destruction of the cell vessels, the released fixed electrolyte (gelled sulphuric acid) is as corrosive as liquid.

Avoid the risk of explosion and fire hazard, short circuits !

Attention! Metal parts of the battery cells are always hot, **no tools or foreign objects are to be placed on the battery**.

Under all operating conditions, hydrogen can escape through the ventilation Cap. Ventilate rooms and cabinets sufficiently.

Systemic health hazards !

Indicates several serious hazards for internal organs, e.g.: Respiratory sensitisation. Aspiration hazard. Carcinogenicity, germ cell mutagenicity or reproductive toxicity (CMR).

The installation in non-vented sealed housing is **not permitted**.
To eliminate security risks, the **ventilation requirements of EN 62485-2 : 2019** «Safety requirements for secondary batteries and battery installations. Stationary batteries» must be respected.

Use protective glasses and clothes !

Use protective glasses and clothes when working on batteries. Pay attention to the accident prevention rules as well as DIN EN 62485-3 and VDE 0105 part 1.

No Smoking !

Do not expose batteries to naked flames, glowing embers or sparks, as it may cause the battery to explode.

2.2 Intended use

The rolling stock single cells ZeMaXX are intended for use as a back-up battery in rolling stock vehicles like coaches and multiple power units.
Improper use can result in danger to people and objects. Assembly, operation and service of the batteries must be performed by qualified personnel.

2.3 Leaflet "Information for the safe handling of lead-acid batteries"

For more information on safe handling of lead-acid batteries please read the current EnerSys Information Leaflet "Instructions for the Safe handling of Lead-Acid Batteries". This guidance note provides advice and assistance for compliance with the statutory requirements.

2.4 Classification of warnings

Always observe the warnings under "2.1 General Safety information" when handling the battery. This will reduce the risk of personal injury and the risk of property damage or damage to the environment.
More warnings in this operation manual indicate hazards as well as dos and don’ts that have to be observed and followed in the corresponding modes of operation or during the work described.

Structure of safety instructions:

Icon	**Warning** (= Icon name) Warning text Notes	**Bold** Tags in bold Standard format

3. Product description

3.1 Rolling Stock Single Cells

These Instructions are valid for the following VLRA AGM Single Cells:

- ZeMa200P18
- ZeMa270P12
- ZeMa340P12
- ZeMa450P21

3.1.1 Common Technical Data of the rolling stock single cells **ZeMaXXPxx**

Technology	: VRLA (AGM), TPPL+Sn
Nominal Voltage	: 2 V
Flame retardant battery case	: PC+ABS FR or Estaprop, halogen free V-0 (UL 94), I3 / F2 (NF F 16-101)
Shock and Vibration	: Category 1, Class B (EN 61373)

The single cells are delivered charged and ready for use.

3.1.2 Technical Data: Rolling Stock Single Cells **ZeMa200P18**

Rated Capacity	: 208 Ah C_{10}
Part number	: SR70770206
Dimensions (WxDxH)	: 125 x 157 x 259 mm
Terminals	: M10 x 20 deep, female thread
Weight	: 14.5 kg ±2%

For more technical data take reference to the data sheet:

- Hawker_ZeMaRail_ZeMa200P18_Brochure_01_EN_2021-03-V2.pdf

3.1.3 Technical Data: Rolling Stock Single Cells **ZeMa270P12**

Rated Capacity	: 270 Ah C_{10}
Part number	: 1896504V0CP
Dimensions (WxDxH)	: 83 x 198 x 370 mm
Terminals	: M10 x 22 deep, female thread
Weight	: 16.3 kg ±2%

For more technical data take reference to the data sheet:

- Hawker_ZeMaRail_ZeMa270P12_Brochure_01_EN_2022-09-V1.pdf

3.1.4 Technical Data: Rolling Stock Single Cells **ZeMa340P12**

Rated Capacity	: 340 Ah C_{10}
Part number	: 1898204V0CP
Dimensions (WxDxH)	: 83 x 198 x 435 mm
Terminals	: M10 x 22 deep, female thread
Weight	: 19.5 kg ±2%

For more technical data take reference to the data sheet:

- Hawker_ZeMaRail_ZeMa340P12_Brochure_01_EN_2022-09-V1.pdf

3.1.5 Technical Data: Rolling Stock Single Cells **ZeMa450P21**

Rated Capacity	: 450 Ah C_{10}
Part number	: 1890507V0CHA
Dimensions (WxDxH)	: 137 x 198 x 370 mm
Terminals	: M10 x 22 deep, female thread
Weight	: 27.9 kg ±2%

For more technical data take reference to the data sheet:

- Hawker_ZeMaRail_ZeMa450P21_Brochure_01_EN_2017-12-V1.pdf

3.2 Illustration and Parts of a Cell

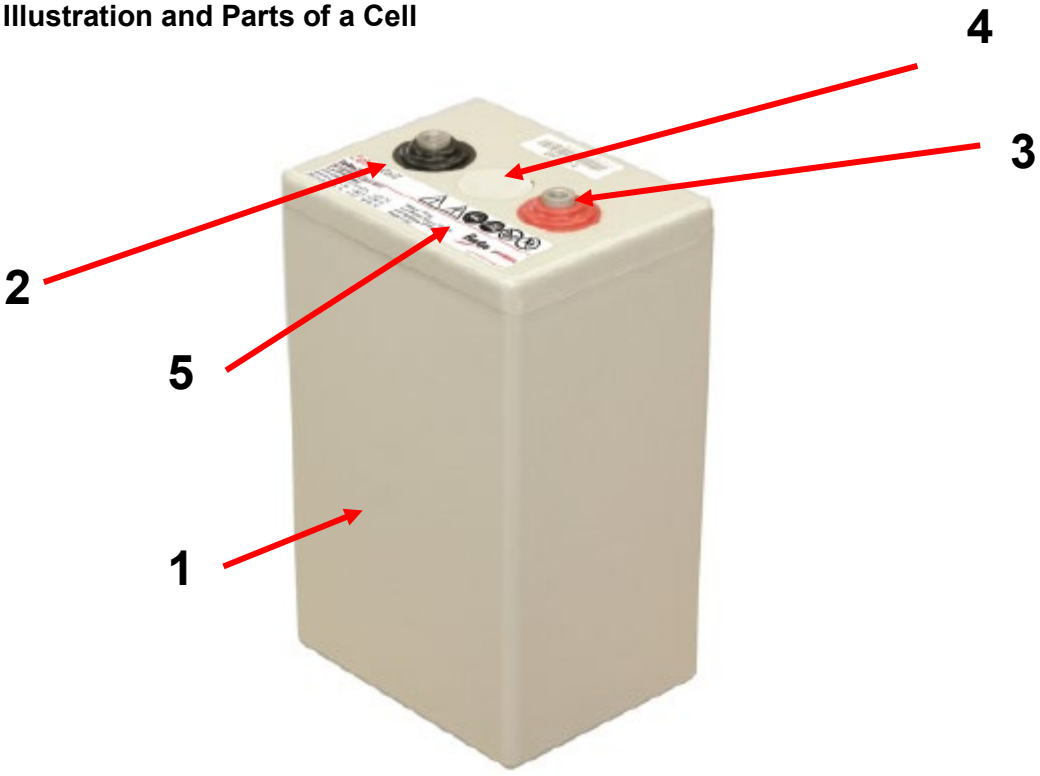


Figure 1 : Parts of a 2V ZeMaRail Single Cell

Pos.	Subject	Quantity
1	Cell case	1
2	Cell lid	1
3	Terminals	2
4	Flame barrier at vents	1
5	Type label	1

3.3 Charge and Discharge Parameters

ZeMa*Rail* Single Cells ZeMaXXPxx				
U_N	:	**2**	**V**	Nominal voltage
C_{10}	:	**XX**	**Ah**	Rated capacity to 1.8 V at 20°C until 1.8 V
I_{10}	:	**XX/10**	**A**	Discharge current for C_{10}
I_{Load}	:	**acc. Load profile**	**A**	Discharge current acc. Customer load profile
U_{final}	:	**1.8**	**V**	End of charge voltage at I_{10} (until 1.8 V)
$I_{Charge\ max}$	:	**0.45*XX**	**A**	Charge current for IU or IU0U-charging (minimum for cyclic use: 0.25*XXA)
U_{Boost}	:	**2.4**	**V**	Boost level voltage setting at 20°C (2.40 V)
U_{Rail}	:	**2.3** **to 2.35**	**V** **V ± 1%**	Lower level or constant voltage setting for rail applications at 20°C, 2.30 … 2.35 V (low … high cyclic use)
I_{switch}	:	**0.012*XX**	**A**	
U_{float}	:	**2.29**	**V ± 1%**	Float level voltage at 20°C, 2.29 V (> 24h)
Manual temperature compensation of the charge voltage:				
		-4	**mV/°C**	Electrolyte – temperature between -20°C till +45°C (-4 mV/per cell)

3.4 Operating modes and special operating modes

Further information about these modes can also be found in chapter 7.1 “Operation modes”.

3.4.1 Standby (parallel) operation (charge)

As long as the power supply is ensured via the main power supply, the backup battery is continuously charged. The charging current will be determined by the charging status of the battery. With continuous charging the current drops to very small values to maintain the battery fully charged.

3.4.2 Battery operation (discharge)

When the power supply is switched off or fails, the supply to DC loads will come from the battery. The backup time will depends current demand from the DC loads.
To avoid damaging deep discharge, the loads must be separated before reaching the final discharge voltage of the battery.

3.4.3 Storage and workshop operation (recharge, capacity testing, etc.)

During storage or service, the battery can be disconnected from charging and any loads, the battery will show its open-circuit voltage on its terminals.
The state of charge is also to be monitored during the storage of the battery. Possibly you might hold it at full charge by a workshop charger operating with float voltage.

4. Transport and storage

4.1 Receiving

Upon receipt of a shipment, check that the items delivered are undamaged and match the carrier's Bill of Lading. Report any damage or shortages to the carrier. Your supplier is not responsible for shipment damage or shortages that the receiver does not report to the carrier.

4.2 Storage Conditions and Time

If a battery cannot be installed immediately it should be stored in a clean, cool, dry area.

4.2.1 The batteries must not be stacked. We recommend, for simple handling during transport and storage, to place the cells on a pallet and fix them. Protect the cells from dust and contamination with a plastic cover.

4.2.2 The relative humidity of max. 90% RH (non-condensing) should not be exceeded.

4.2.3 The storage ambient temperature should be between -15°C and 30°C, details see also 4.2.5.

4.2.4 Do not expose the cells and batteries permanently to direct sunlight.

Care must be taken on cleanliness. When cleaning, please note the remarks in chapter: Cleaning and visual inspection.

4.2.5 During storage batteries lose capacity through **self-discharge**.

High temperature increases the rate of self-discharge and reduces the storage life.
The chart below shows the relationship between open-circuit voltages (OCV) and storage time at various temperatures:

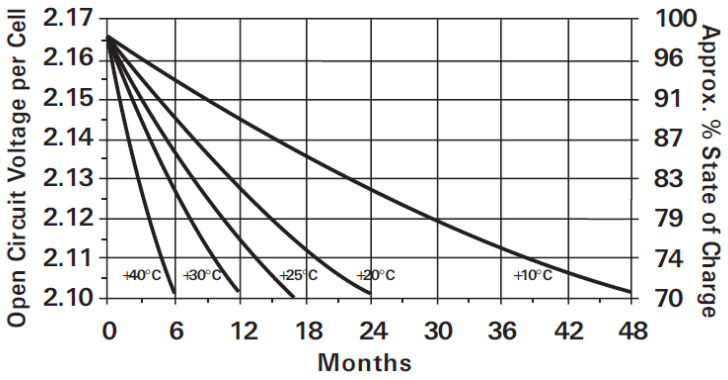


Figure 2 : Self-discharge: OCV per cell representing approx. % of SOC

The maximum storage times before a freshening charge is required and recommended open circuit voltage audit intervals are:

Temperature (°C)	Storage Time (Months)	OCV Audit Interval (Months)
+10	48	6
+15	34	6
+20	24	4
+25	17	4
+30	12	3
+35	8.5	2
+40	6	2

ZeMaXXPxx single cells must be given a freshening charge when the cell voltages approach 2.10V or when the maximum storage time is reached, whichever occurs first.

4.2.6 If the voltage of the individual cells is reduced below 2.02 V, storage damage may have occurred. Before using such batteries, they should be recharged and tested in a workshop.

5. Mounting

5.1 Preparing for installation

The cells are charged and delivered ready for use. Before assembly please conduct the following testing and preparation steps:

5.1.1 Check that no damage has occurred during delivery and make sure that no damage was caused during transportation.

5.1.2 Check the open-circuit voltage (OCV) of the cells. A cell voltage below 2.10 V, indicates a bad state of charge of the cells. Make sure that the batteries are charged under constant load 72h before (or just after) the installation. A cell voltage below 2.02 V indicates irreversible damage likely caused during transport and storage, and a check or replacement of the affected unit is recommended.

For cleaning the batteries please note the instructions under:
Fehler! Verweisquelle konnte nicht gefunden werden.

5.2 Installation works

Take note of the contents of this manual prior to installation and record them for later consultations.
During mounting, follow the instructions below:

5.2.1 The insertion of the battery tray is carried out in accordance with the instructions of the vehicle manufacturer and any internal instructions of the railway operator. The work must be performed by trained personnel.

5.2.2 Due to the heavy weight of lead-acid batteries a suitable mechanical lifting truck or crane for handling must be used.

5.2.3 Do not use grease on the frame rails or the end terminals. If a protective grease is necessary for the connections, use **only** pure silicone grease (risk of damage to plastic cases).

5.2.4 **The installation in non-ventilated sealed housing is not permitted**. Verify during installation that the battery compartment of the train allows sufficient air exchange.

5.2.5 During installation (and later operation) of their moving stationary battery system is essential to comply with the applicable regulations. In particular, we refer to:

- ❑ EN 62485-2 : 2019 «Safety requirements for secondary batteries and battery installations»
- ❑ Local regulations for Low Voltage Installation.

5.2.6 Open and secure the switch of the electrical installation to the battery box, so for the assembly the battery lines to the charging rectifier and the loads are fully isolated and the battery voltage is “floating”.

5.2.7 Also a battery disconnected from the charger or the external circuit supplies **live electrical voltage** and small quantities of Oxyhydrogen gas can escape. Prevent open flames, electrostatic discharges, sparks and short circuits with clothing, jewellery, watches and tools during the installation.

5.2.8 Verify that during operation **sufficient air circulation will ensure the dissipation of heat out of the compartment.** Check that any ventilation filters are not blocked.

5.3 Assembly inspection, Connection

Note the following points when installing:

5.3.1 Follow chapter "6 Commissioning" as well as the instructions of the system supplier (battery box, auxiliary power supply).

5.3.2 Check the polarity of the battery and cells. Cells or batteries connected in series are connected from the negative to the positive pole of the following battery.

5.3.3 Connect the battery only after checking the correct battery polarity to the charger or to the consumer load.
If they connect, there may be a small spark depending on the switching arrangement.

5.3.4 Verify that the batteries are properly secured in their position.

6. Commissioning

6.1.1 The commissioning of the entire system must be carried out as specified by the vehicle manufacturer and equipment suppliers (auxiliary power supply) as well as the internal guidelines of the train operator.

6.1.2 Make sure that the settings and parameters for the charge and monitoring correspond with the information in these operating and service instructions. Regarding charging, battery operation, inspection and monitoring this operating and service instructions must be followed.

6.1.3 Now close the circuit breaker to the battery box according to the instructions of the vehicle manufacturer and equipment suppliers.

6.1.4 Please check the charging voltage and verify that **during the constant voltage charge the recommended voltage value can be measured at the end terminals of the battery**.
Note that this value depends on the given charge- and temperature conditions and during inspection the charge must be in the constant voltage phase. This depends on the state of charge of the batteries and will apply latest after 9 hours of charging.

6.1.5 After the inspection of the charge, perform a discharge with loads of the vehicle and check the **function of the deep discharge protection relay** when the final discharge voltage is reached. Register the average power consumption, the discharge duration and the final discharge voltage (minimum voltage on the battery before the disconnection).

6.1.6 Check if the battery is free of loads after the shutdown. It is important to note that such loads can deep discharge the battery. If there is no charge in due time the load must be switched off manually. Fully recharge the battery immediately after the test and hold the battery for at least 48 hours on continuous charge.

7. Operation

Here you will find important information on the normal and safe operation of the backup batteries. Batteries have a limited service life and are consumed by the operation. Apply the information for the charging in order to achieve a long service life.

7.1 Operation modes

The rolling stock battery as backup battery is an important part of the auxiliary power supply of the coach or a multiple power unit. The battery is usually installed in **standby operation** and is therefore always connected to the electrical installation.

The battery has a strong influence on the voltage in the DC supply line. As long as the pantograph is lifted (power supply from the contact line is switched on) the power converter is working with the charging voltage. It supplies the loads with electricity and simultaneously charges the battery with a current according to the load parameters and their state of charge. If the pantograph is lowered, the battery acts as a power source (discharge) and provides the loads with energy. This reduces the voltage on the DC bar with the depth of discharge of the battery. To avoid damage to the battery, over the discharge time the load management will cut off parts of the load and the deep discharge protection will disconnect the load from the battery when the end of discharge voltage is reached.

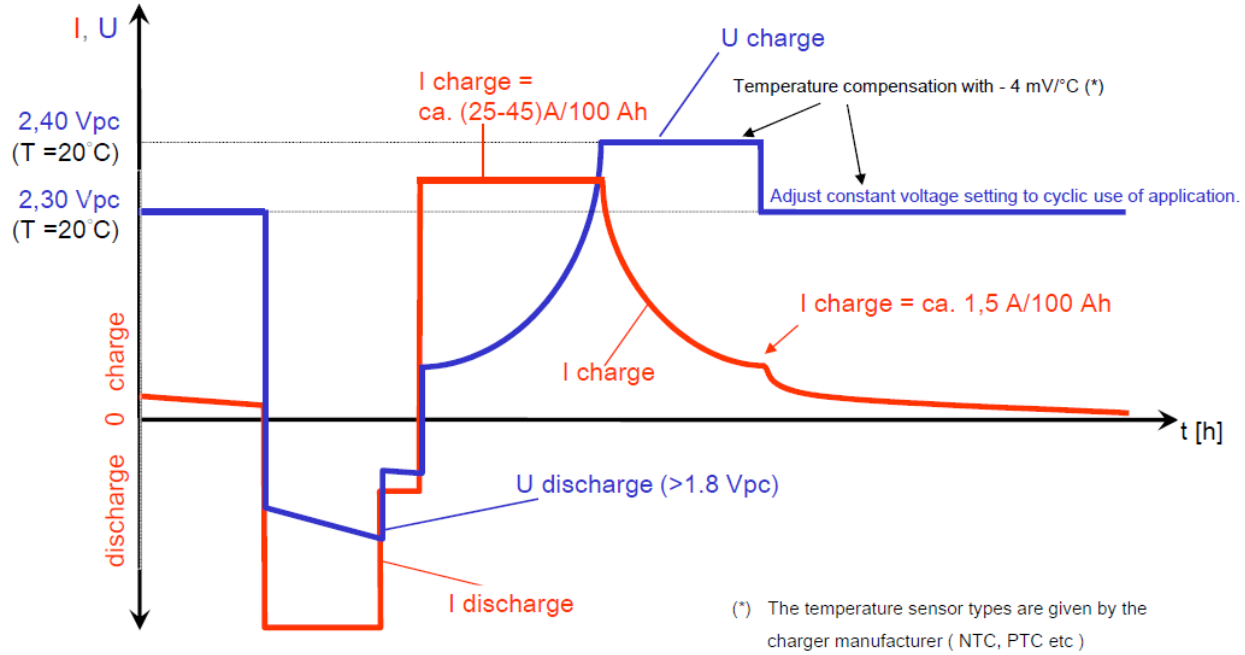


Figure 3 : Operating modes charge-discharge-charge with IU0U charging characteristic

7.2 Charging of the rolling stock battery

These batteries should be charged with the described IU0U or IU charging method (according to DIN 41 772 and DIN 41773-1). Otherwise there is a risk of damage to your battery.

7.2.1 For operation in rolling stock vehicles the battery should be charged following EN 50547 “Railway applications – Batteries for auxiliary power supply systems” and in accordance to **IU0U charging - characteristic** (DIN 41772) with temperature compensation (see also: 7.2.3 “Temperature compensation of the charging voltage”). This complex charging technology combined with temperature compensation and state of charge depending on boost charge allows a fast recharge and a gentle continuous charge of the backup

7.2.2 For For rolling stock batteries with 2V ZeMaRail single cells, the 2 level battery charging characteristic is recommended. The IU0U charge starts with a constant current phase whilst the voltage increases as a function of the state of charge (SOC) of the battery. At about 80%SOC the battery reaches the voltage of the boost-charging phase and the charge current will reduce. At a SOC of about 95% the current is so low that the charge control switches to the constant voltage charging. The battery will then get fully charged and a small charging current remains to compensate the self-discharge and recombination. The reference temperature is 20 ° C.

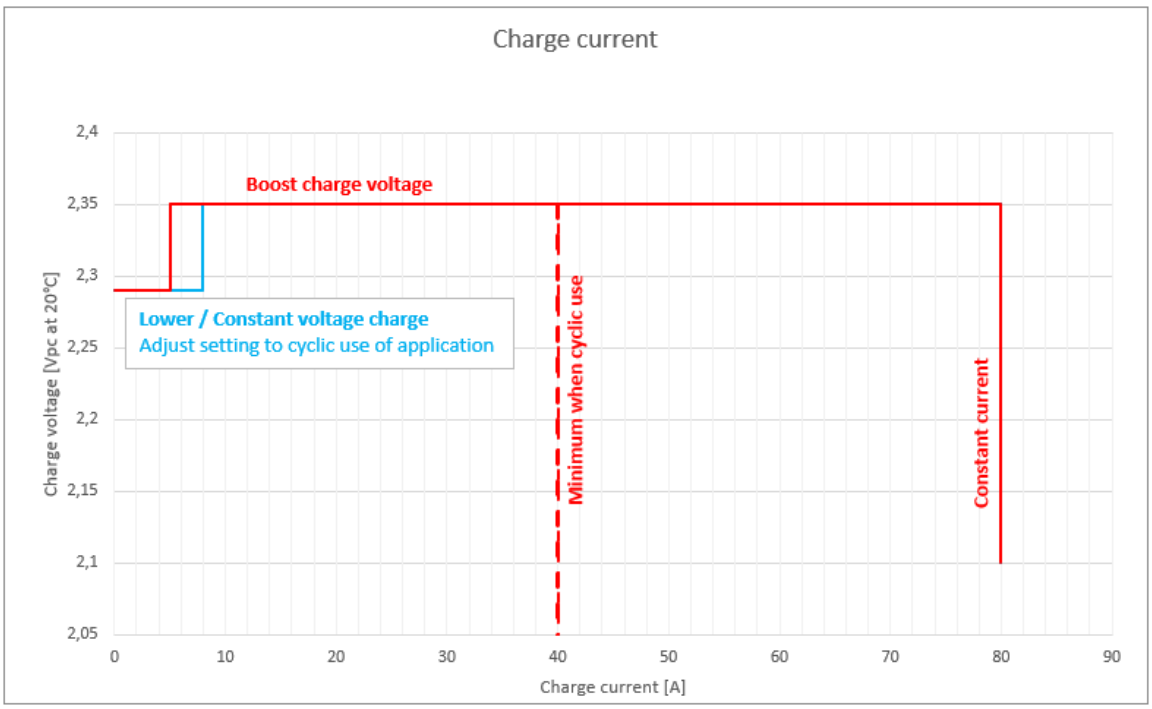


*Figure 4 : Charging characteristic IU0U charge for ZeMa200P18**

Parameter ZeMa200P18* at 20°C	Cell 2V	Battery 24V	72V	108V
Max. charging current*	80 A			
Boost level voltage U_{Boost}	2.40 V	28.80 V	86.4 V	129.6 V
Lower level voltage U_{Rail}	2.30 V	27.6 V	82.8 V	124.2 V
Temperature compensation	-4 mV/°C	-48 mV/°C	-144 mV/°C	-216 mV/°C

* Charging current relates to cell capacity, for other cells refer to data sheet

The switching between the charging voltages for boost level charging U_{Boost} and for (lower) constant voltage charging U_{Rail} is carried out according to the following criteria:

Downshift from U_{Boost} to U_{Rail}: When charging current falls under 3A (± 1A)
Upshift from U_{Rail} to U_{Boost} If charging current increases over 5A (± 1A)

For temporal limitation of the boost charging, a maximum boost charging time of 12 hours must be implemented beside the charging current, as switching criteria. Charging interruptions shorter than 2 minutes should not restart this time.
When switching to (lower) constant voltage charging U_{Rail} the voltage should be reduced with a ramp, so that a charging current greater 0A remains.
When the operating of your train loads the battery with daily discharges >5% DOD adjust the lower charging voltage of your system.

7.2.3 Temperature compensation of the charging voltage

The operating and ambient temperature affects the battery life. It is therefore recommended that the charger detects the battery temperature with a sensor and compensates the charging curve as specified in section 3.1.1 “Common Technical Data of the rolling stock single cells **ZeMaXX**”.

If continuous charging voltage U_{Rail} operates without temperature compensation and the **ambient temperature of your battery installation should permanently be outside the range of 18 °C to 25 °C**, correct the charging voltage U_{Rail} according the following chart manually:

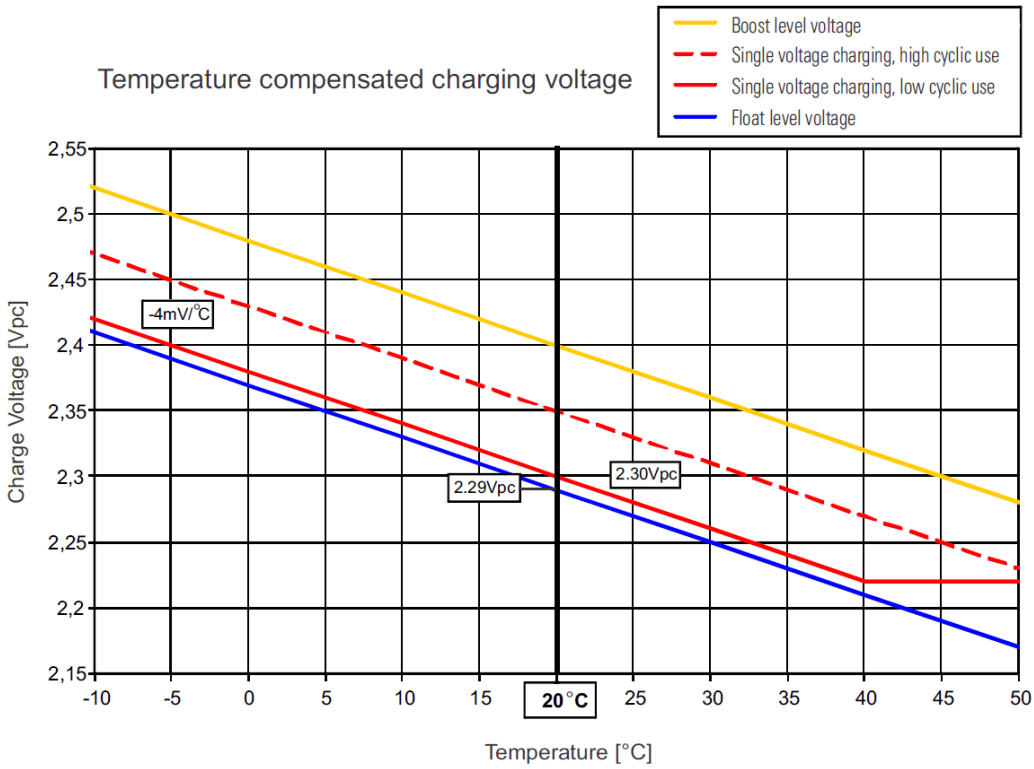


Figure 5 : Temperature compensated charging voltage

Adjust the setting of the manual temperature compensation with a negative gradient of -4m V/°C / cell for the temperature range from -25 °C to 40 °C. This corresponds to -48m V/°C for a 24V battery system.
The allowed tolerances ±1% for the respective constant voltage charging U_{Rail} remains.

Example:
A 24V-Battery with low cyclic use (2.30 Vpc) and an average electrolyte temperature of 10 °C would be charged with 28.08 V.

12 cells * 2.30 Vpc + (-10 °C * -0,048 V/°C) = 28.08 V

Attention!

Increased operating temperatures will lead **to premature aging** of accumulators.

Practical tests show that an increase of 10 °C of the battery temperature from the nominal temperature of 20 °C causes a 50% reduction on service life.

7.3 Battery operation

Backup batteries for rolling stock of the type ZeMaXXPxx may only be discharged down to the specified **discharge voltage U_{final}**. For the values of your system refer to the „System specific Technical Data“ (see Position "**U_{final}**").

After a discharge **recharge the battery system immediately** in accordance with the regulations described in section before. Implicitly **avoid longer holding times without full charge**, this will prevent damaging your system.

In **the event of an interruption** (e.g. equipment failure) a discharge to 1.65 Vpc is allowed. Thereafter the battery has immediately to be fully recharged and the total voltage has to be checked. In case of repeated failing, we recommend to maintain in the workshop a preventive full charge of the battery according to 8.6.2 “Equalization charge”.

Risk of explosion !

During all operating conditions **hydrogen can escape** from the cells valves.

Venting spaces and cabinets in which batteries are operated sufficiently well

Avoid the risk of explosion by strictly following the ventilation rules of EN 62485-2 : 2019 "Safety requirements for secondary batteries and battery installations"

When the train is set out of service a discharge (by consumer loads) must be avoided. Keep the batteries either on float charging or process them in accordance with chapter 9 “Decommissioning in the vehicle”.

8. Service

The 2V ZeMa*Rail* single cells for rolling stock batteries are designed with sealed maintenance-free cells (VRLA) filled with AGM fixed electrolyte. No water must be refilled into these cells.

Attention!

It is prohibited to open the cell housing to fill in water or other substances.

For a long lasting hassle-free operation it is important that the charging technology is correctly parametered to the operating conditions. Make yourself familiar with the

operating conditions and assure to know and understand the used charging technology. (Also note the information in chapter 7 "Operation".)

Make sure that only qualified and protected personnel have access to the battery system and that they are familiar with the contents of these operating and service instructions, and in particular with the safe handling instructions of batteries described in chapter 2 "Safety". A battery is **always live**, even when it is disconnected from the charger or the external circuit. Pay attention during inspection and repairs on live parts and avoid open flames, static discharges, sparks and short circuits with clothing, jewellery, watches and tools. Ensure insulated tools are used.

8.1 Inspection

Periodically check and verify that the battery system functioning correctly.

Preventive maintenance procedure	See Detail	Interval
Constant voltage of charging at the terminals of the battery	8.1.1	At commissioning, later every 4 to 12 months
Cleaning and visual inspection	8.2	Every 12 months

8.1.1 Checking of charge and cell voltage

List of tools for this inspection action:

Designation	Comments
Digital voltmeter with thin measuring tips (Measuring hole connector cover 2mm)	DC voltage measurement with display precision 0.001 V at cell voltage
DC-Clamp Meter	Cable diameter approx. 15mm for measured values <1A and <60 A
Temperature Meter	possibly with an external sensor
Tool for accessing	According to documents of the corresponding battery box

Check and **adjust, at least once a year, the constant charge voltage** in accordance with the instructions of the charger manufacturer. At the same time, measure and record the individual cell voltages.

The following measurements should be regularly carried out and recorded. Select the measurement interval corresponding to the functional importance of the battery system (e.g. its relevance to the safety of persons). For projects with Battery Monitoring System BMS this function may be partly carried out automatically and a realisation of these measurements is only necessary in case of an error message.
Check the setting of the voltage controller of the charger every 6 to 12 months.
Integrate this test in an inspection modus with an appropriate interval.

Parameter	Measurement	Measuring interval
Continuous charge voltage at end terminals of the battery *	$>U_{Battery}$	On start-up, then every 4 to 12 months
Continuous charging current *	<3 A	After full charge every 6 to 18 months
Cell voltages*	>2 V	At commissioning, then every 6 to 18 months
Battery temperature	°C	Once in the summer and upon request *

* Conduct your electrical measurements, if the charge is in continuous charging / constant voltage mode, provided the charge was not interrupted for a period of 9 hours. Log it the battery temperature for better interpretation of your measured values.

Verify the charging voltage of the charger and convince yourself that the constant charging voltage at the battery terminals corresponds with the recommended value. (Please note that for this case the value depends on the current charge and temperature conditions, and that the constant charging voltage is already pending.)
In case of deviation adjust the charging scheme according the instructions of the charger manufacturer.

Store the collected data related to the battery system and analyse them over the time of operation. Significant deviations should be observed, for a structured approach please use the “Decision tree for analysis of voltage deviations” in 16 (Decision tree)".

When interpreting the measured values for the cell voltages check that the correct charging voltage of the cells at 20 ° C and under fully charged condition is in a tolerance range of ± 0.3 V / per 2V cell. Lower values require attention especially if they tend to continue to decay. This may indicate that there is an internal short circuit in one of the cells. During the service life expect higher cell voltage values to decline.

8.2 Cleaning and visual inspection

List of tools for this service action:

Designation	Comments
Damp cloths	
Tool for accessing	According to documents of the corresponding battery box

The batteries must be kept clean and dry.

Risk of sparking caused by static discharge!

Clean dirty surfaces of batteries and cells with a **water-dampened cloth**. Other cleaning agents or other substances shall not be used.

Lead-acid batteries should not be cleaned with a dry cloth or feather dusters.

Use protective glasses and clothes!

Protect the eyes if you come near the battery,
liquids and explosive gases can cause blindness and damage

While **working on batteries** observe the accident prevention regulations, as well as EN 62485-2 and -3 and EN 50110-1.

Risk of case damage!

There is a risk of damage to plastic cases by **chemicals**.

Do not use any sprays, chemicals, solvents or similar to clean the battery.

The system design for rail application often uses fully insulated connectors. This helps avoiding creepage from normal light pollution in the battery container. In the case of heavy soiling use the battery switch to interrupt the charging of the battery. Then disconnect the battery pack with the battery connector and clean the surface with a water-dampened cloth.

Check the cells, the connectors and the tray on defective components: orientation and position of the components, material cracks, signs of overheating, extraordinary marks on valve covers, leaking electrolyte (gel), loose connectors, etc.

Should you clean a dismounted battery with a water jet, you have to use a hose to pump out the water that has collected in the tray. Take care that there is no water in the screw heads of the connectors and that the battery is thoroughly dry before re-commissioning.

8.3 Capacity test

List of tools for this service action:

Designation	Comments
Charger and Discharge Resistor	With matching voltage, currents and connection to your system
Digital voltmeter with thin measuring tips (Measuring hole connector cover 2mm)	DC voltage measurement with display precision 0.001 V at cell voltage
Tool for accessing	According to documents of the corresponding battery box

With a capacity test you can verify the functionality of a battery system. A battery with standard design is operational if the current battery capacity C_{act} is greater than 80% of the rated capacity C_r (Testing according IEC/EN 60689-21/22).

The most informative battery check is a periodic capacity test.

The test discharge is stressing the battery and the **voltage of individual cells must not fall below 1.6 Vpc**.

Secure rapid full charge of the battery before and after the test.

Test the fully charged battery after a pause of 6 hours with a constant current C_{10} for 8h (test of functionality, less stressing) or down to the final voltage representing 1.8Vpc (test for actual capacity).

8.4 Service life of the battery

The 2V ZeMa*Rail* single cells for rolling stock batteries have a limited service life. Cyclic operation consumes the active mass of the positive plates and continuous charge will lead to drying out of the electrolyte.
The end of the battery life is reached when the available capacity at fully charged condition corresponds to only 80 % of the rated capacity. The reduced capacity is indicated by how quickly the voltage drops during battery operation (discharge).The Ah - meter of the battery management system BMS can determine the reduced capacity and will display the end of the service life.

The ZeMa batteries must be operated at all times under the following conditions:

- Maximum energy throughput: Project related
- Average temperature: 20 ° C - 25 ° C
- Maximum operating temperature: up to + 40 ° C

In addition, the requirements, instructions and documentation of the manufacturer of the ZeMa batteries must be complied with at all times.

The ZeMa batteries work in the entire temperature range of EN 50125-1, Table 2, Class T3 (-25 ° C - + 45 ° C). At low temperatures, the charge consumption is reduced and the

battery can no longer be fully charged. Constantly high temperatures accelerate the aging of the battery.

The time depends strongly on the real usage conditions (charging technology, influence of heat, cyclic operation, ...).
For the evaluation of the battery state of health condition a C_5 or C_{10} capacity test can be conducted. Due to the long duration of the test in most cases the battery must be dismounted from the vehicle.
The increase of the continuous charging current is an indicator of the advanced period of use. But it is not a distinct sign of reaching the end of the service life.

We recommend that the rail operator defines a maximum expected service life of the battery in their vehicles and operating conditions and to preventively replace the rolling stock by this criterion.

8.5 Replacement of the battery

In order to achieve a short downtime of the vehicle in the event of faults, that cannot be remedied within a short time or when the maximum period of use is reached, we recommend a rapid exchange of the battery system in the vehicle.

8.5.1 Dismantling of the batteries

Follow the instructions in chapter 10.1 "Disassembling".
Log the operation counter data, which read at the BMS.

8.5.2 Installation of replacement batteries

Follow the instructions in chapter 5 “Mounting” and chapter 6 ”Commissioning”.
Reset the counters in the BMS (or to the intermediate values of the replacement battery).

8.6 Repair and refurbishing (Curative service)

Avoid the risk of explosion and fire hazard, short circuits!

Attention! Metal parts of the battery cells are always hot, **no tools nor foreign objects are allowed** to be placed on the battery.

Under all operating conditions, hydrogen can escape through the ventilation Cap. Sufficiently ventilate rooms and cabinets.

It is **not permitted** to charge in closed and unventilated rooms.
To eliminate security risks, the ventilation requirements for workshop charging according to **EN 62485-3:2015** “Safety requirements for secondary batteries and battery installations, Part 3: Traction batteries” must be respected.

When working with a battery charger make sure you follow the instructions of this equipment and verify correct parameter settings.

8.6.1 Recharging the battery in the workshop

For the recharging of the battery in the workshop at 20 ° C use a constant current charging of minimum I_{10} (ZeMa200P18*: 20.8 A) and the trickle charging voltage of 2.29 Vpc.

Charge with *I_{10} = 20.8 A	Cell 2V	Battery 24V
Constant voltage level = Trickle charging	2,29 V	**27.5 V**
Boost charge voltage (max. 10h)	2.40 V	**28.8 V**

* Charging current relates to the cell capacity, for other cells refer to the data sheets

If you are using a modern IU0U-Charger you can set boost charge voltage to 2.40Vpc. Make sure the 1st phase is limited to 10 hours.

If the battery temperature in the workshop deviates permanently more than 5°C, the charge voltage should be adjusted in accordance with 7.2.3 “Temperature compensation of the charging voltage”.

The recharging duration for a battery depends on its discharge state (depth of discharge, discharge time). Recharging a completely discharged battery with the IU charging will take:

approx.	9 Hours for	75% of the capacity
approx.	14 Hours for	85% of the capacity
approx.	30 Hours for	100% of the capacity.

With higher charging current and a boost charge phase you can expect shorter duration.

When the battery is fully charged with the recommended charge voltage the continuous charging current is about 1mA/Ah. Over of the service life of the battery this trickle charging current can increase up to 6mA/Ah. The prolongation of the trickle charging during 48 to 72 hours will help to maintain the electrochemistry of your battery.

8.6.2 Equalization charge

The 2V ZeMa single cells do not require periodic equalization charging. In VRLA batteries stratification should not occur. After a deep discharge or when voltage differences of the cells indicate a sulfation, an equalisation charge can be considered.

This treatment is performed on the previously fully charged battery after a break of at least one hour (gassing, cooling down) and requires a special charging rectifier.
The procedure applies for a limited period a small charging current (<10% I_{10}) to the series-connected 2V cells. During this charge with constant-current the voltage limit is increased to 2.8 Vpc.

Equalization charge	Charging current	Duration	24V System
ZeMa200P18	max. 2.08A	**max. 10 h**	33.6V
ZeMa270P12	max. 2.70A		
ZeMa340P18	max. 3.70A		
ZeMa450P21	max. 4.50A		

During this procedure you have to observe the battery for thermal reaction. If a battery cell exceeds the temperature of 45°C you must interrupt the equalisation charge.
Limit the duration of the equalisation charge to 10 hours. Long exposure to equalisation charge can damage the battery and consume a considerable share of its service life.

8.6.3 Recharging after deep discharge

Recharging after an accidental deep discharge may take too long in the vehicle and disrupt the daily service.
Recharge a completely discharged battery as soon as possible in the workshop at 20°C with a reduced current of I_{24} (ZeMa200P18*: 9.8 A) for 26 hours. Limit the charge voltage to 2.35 Vpc:

After this step adjust the charging rectifier back to trickle charging voltage of 2.29 Vpc. A subsequent recharging for at least 72 hours will help to maintain the electrochemistry of your battery.

Recharge current I_{24} = 9.8 A	**Cell 2V**	**Battery 24V**
Voltage limitation, for 26h	**2,35 V**	28,2 V
Trickle charge, min. 72h	2,29 V	**27,5 V**

* Charging current relates to the cell capacity, for other cells refer to the data sheets

After a correct recharge of the battery, it will then be ready for service. With a capacity test (8.3 "Capacity test") you can verify the functionality. Note that each deep discharge is stressing the battery and consumes its life endurance over proportionately.

8.6.4 Mechanical damage caused by force (E.g. accidents)

Falling, a strong shock or contact with aggressive chemicals, can demolish the case of the cells, conducting electrolyte can escape and internal short circuit can occur.

Caution risk of short circuit!

All **exposed metal parts** of the battery cells are hot.
Danger of injury by electric shock or short circuit.

Touch the battery only on the plastic surfaces.
Do not place any foreign objects or tools on the battery.

Use protective glasses and clothes!

Protect the eyes if you come near the battery,
liquids and explosive gases can cause blindness and damage

While **working on batteries** observe the accident prevention regulations, as well as EN 62485-2 and -3 and EN 50110-1.

If the damaged battery is connected to a circuit: Disconnect the battery with the installed electrical isolation device from the load circuit. (Battery switch; when de-energized: Emergency, connector battery connector, possibly cell connectors)

In case of accidents neutralize the leaking electrolyte with lime. The remains are to be environmentally friendly disposed of and by no means can the material be poured into the waste.
Consult the leaflet “Instructions for the Safe Handling of Rail Batteries”, for further questions contact our customer service!

If any Acid splashes into eyes or onto skin rinse under clear running water. After contact with eyes seek immediate advice from a medical doctor, please also contact your doctor after serious skin contact.

Caution!

Lead-acid batteries are **very heavy!**

Pay attention to safe installation and use only suitable handling equipment and hoists.

Special care is required when the battery tray has cracks or mechanical damages.

8.6.5 Replacement of battery segment or individual cells

Designation	Comments
Lifting and other mechanical tools	Depending on system design
Insulated torque wrench	Nuts according system design
Scotch Brite sponge	Cleaning of contact surfaces

An Assembly drawing and part list can be found in your system documentation.
If your system is composed of several batteries (E.g. in trays) or with individual cells in series and you have to partial replace a segment or an individual cell in the service workshop, please read the following information:

- ❑ Combine only batteries or cells that are in the **same state of charge**. It is best to undergo the various groups a previous 72h charge with float level charging voltage and ensure that they all are fully charged.
- ❑ Combine only batteries or cells with approximately the **same age** and when reusing cells select cells from similar applications. Our experience shows that new cells prove problematic when installed with batteries that have already been used for more than 2 years.

Work with **insulated tools**, when assembling the cells check the correct polarity and mount the connectors correctly (Refer to system drawing). During assembly, make sure that all contact surfaces are clean. Residues of the screw lock mass, can be removed with a dry Scotch Brite sponge.

Use only new and unused terminal screws with screw lock (grey-blue mass in the thread). Do not exceed the recommended **tightening torque** for the terminal screws:

Cells	Tightening torque	Unit
ZeMa200P18, ZeMa270P12, ZeMa340P12, ZeMa450P21	25.0 ± 0.9	**Nm**

The terminal screws should be tightened quickly when screwing, otherwise the screw lock cures and ordinary tightening can not be performed.

9. Decommissioning in the vehicle

In the vehicle the back-up batteries will always be recharged to 100% SOC. Before a vehicle is removed from service, this charge should be completed.
Make sure that the charging equipment has adjusted itself to the continuous charging level and that the battery charge current has dropped to the low trickle charge current.

If you take the vehicle out of service, disconnect all loads from the battery. Thus you avoid damaging deep discharge of the battery and when recommissioning a high capacity is available. For Decommissioning of the vehicle follow the instructions of the train manufacturer and of the railway operating company. For "Recharging" follow the instructions given in chapter 4.2.5.

9.1 Preparation for storage

Should you store a working battery pack out of the vehicle, make sure that it is fully charged with a 48-hour charge in the workshop (see chapter 8.6.1 “Recharging the battery in the workshop”).

During storage, follow the instructions from chapter “4 Transportation and storage”.

10. Disassembling

Before disassembly, take note of the contents of this manual and follow the instructions below:

10.1 Disassembling

10.1.1 Please follow the instructions of the vehicle manufacturer and any internal instructions of the railway operator when removing the battery pack out of the vehicle. The work must be performed by trained personnel with appropriate safety equipment.

Caution risk of short circuit!

All **exposed metal parts** of the battery cells are hot.
Danger of injury by electric shock or short circuit.

Touch the battery only on the plastic surfaces.
Do not place any foreign objects or tools on the battery.

10.1.2 Open and secure the circuit breaker of the electrical installation to the battery box, so that the dismantling cables are “floating” and isolated from the charging rectifier and the consumer loads.

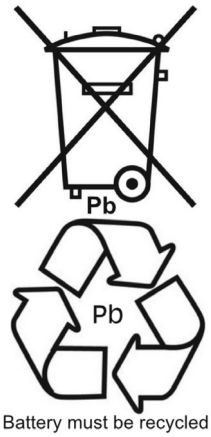
10.1.3 Due to the high weight of lead-acid batteries, you must use a suitable mechanical lifting device.

10.1.4 Even at the end of the service life and disconnected from the charger or the external circuit a battery is **live**. During disassembly avoid open flames, electrostatic discharges, sparks and short circuits with clothing, jewellery, watches and tools. Use insulated tools.

10.1.5 Insulate and secure the connection cables of the vehicle during your work.

11. Recycling and Disposal

Dismantle a battery keeping in mind the risks that are described above. Provided that the battery terminals are undamaged the battery will be protected against possible short circuits. Make sure that no tampering of the battery can be performed whist the battery is stored or sent for recycling.



Battery must be recycled

Environmental Risk!

Risk of lead pollution.

Used batteries are considered as special waste when recycling is required. Batteries are marked with the crossed out wheeled bin and the recycling symbol and may not be added to household waste. For proper disposal contact our customer service.

ZeMa*Rail* single cell batteries are recyclable. Scrap batteries must be packaged and transported in accordance with prevailing transportation rules and regulations. Securely pack them and attach the required Transportation Security Information. To simplify the collection and recycling or re-processing process, spent lead-acid batteries must not be mixed with other batteries.

11.1 Recycling

Material	Mass in %	Remarks
Case, AGM separator	~ 7	90 % recyclable
Lead (Grid, active mass)	~ 64	100 % recyclable
Sulphuric Acid	~ 29	100 % recyclable

11.2 Disposal

Scrap batteries must be disposed of in accordance with local and national laws by a licensed or certified lead acid battery recycler.
Please contact our point of sale for supporting you in taking back spent batteries and render them to the secondary lead smelters for processing.

12. Troubleshooting

Rolling stock batteries with 2V ZeMaRail single cells will operate very reliably if the charging conditions are correct and correctly adjusted to the operating conditions in the train.

12.1.1 A failure of an individual cell or the battery usually leads to a reduced capacity of total battery and appears to the operator in a reduced backup time in battery mode (“Battery operation”) :

- ❑ Load groups will switch off faster because the battery discharge voltage U_{final} is reached earlier or
- ❑ Too little capacity for lifting the pantograph or starting up of the train. (The battery would respond to the higher power consumption with a voltage dip).
- ❑ A BMS (Battery monitoring system) could detect an unbalanced behaviour between individual battery parts if the discharge voltage of a single cell drops down too early.

12.1.2 To allow later analysis, we recommend in case of a failure to measure and record the individual cell voltages. We also recommend recording the conditions under which you made these measurements:

- ❑ Was the battery charging or discharge current or is the battery disconnected from the vehicle (if so what was the duration?)
- ❑ Estimated state of charge of the battery
- ❑ Temperature of the battery. Pay attention to deviations of individual cells.
- ❑ Low voltages of individual cells during discharge can indicate an internal cell short-circuit or over-discharging.

12.1.3 Following such a failure, it is recommended to charge the batteries as soon as possible.

According your operating conditions decide whether this charge should be made in the vehicle or in the workshop. **In the vehicle** avoid discharges by battery operation for one week by minimizing disconnection of the vehicle from the power line.
More time intensive - but better and safer - is to charge the battery **in the workshop** ensuring a full charge over 72 hours according 8.6.1.

12.1.4 If you decide to dismount the battery, measure the open-circuit voltages of the cells before connecting to the charge.
After 24 hours the open circuit voltage is an indicator of the state of charge of a cell:

- ❑ Voltages above 2.14 Vpc are equivalent to 100% charge.
- ❑ Values less than 1.97 Vpc correspond to a residual charge of less than 20% or a discharge from over 80% of capacity (depth of discharge DOD >80%).
  If most of the cells are discharged to that depth, we recommend a charge in accordance with the Section 8.6.3 “Recharging after deep discharge”.

For assessing the state of health of the cells, measure after 3 days at the end of the battery charging according to section 8.6.1 “Recharging the battery in the workshop” the individual cell voltage during trickle charge. If the cell voltages are not within a window of ± 0.3 Volt, continue the charge and repeat the measurement after 10 completed days. Rate the cell voltages in accordance with the “Decision tree for analysis of voltage deviations” in 16 “

12.1.5 To check the functionality and the battery capacity, perform a discharge in accordance with Section 8.3 “Capacity test”.

12.1.6 If individual cells show a fault and should be replaced, proceed according Section 8.6.5 “Replacement of battery segment or individual cells”.

12.1.7 If you continue to operate the batteries in the train or if a fault can’t be found on the dismounted battery, check and verify the conditions of use and the proper functioning of the battery system. Follow it to the information in Section 8.1.1 “Checking of charge and cell voltage”

13. Validation

Preparation
Hagen, 23th November 2022

Gordon Babock
Global Product Manager MP Specialties

14. Document History

04.01.2023 First issue of this document

15. Remark on the Classification

This document and its appendixes are provided to you as PDF – file. The documents have to be processed according to their classification (**public**/restricted/confidential) and may only be disclosed with this note. Observe protective note DIN ISO 16016!

Rail Engineering
Dieckstrasse 42
DE-58089 Hagen

Tel. +49 (0) 2331/372 591
Fax +49 (0) 2331/372 804

www.enersys.com

16. Appendices

Appendix A1: Information for the Safe Handling of Lead-Acid Batteries

Title: Information for the Safe Handling of Lead-Acid Batteries
File: Information_for_the_Safe_Handling_of_lead-acid_batteries_EN_Dec_2016.pdf
6 pages (First published Jan. 2013)

Appendix A2: Data sheet ZeMa*Rail* ZeMa200P18

Title: Data sheet ZeMa*Rail* ZeMa200P18
File: Hawker_ZeMaRail_ZeMa200P18_Brochure_01_EN_2021-03-V2.pdf
4 pages, download from www.enersys.com

Appendix A3: Data sheet ZeMa*Rail* ZeMa270P12

Title: Data sheet ZeMa*Rail* ZeMa270P12
File: Hawker_ZeMaRail_ZeMa270P12_Brochure_01_EN_2022-09-V1.pdf
4 pages, download from www.enersys.com

Appendix A4: Data sheet ZeMa*Rail* ZeMa340P12

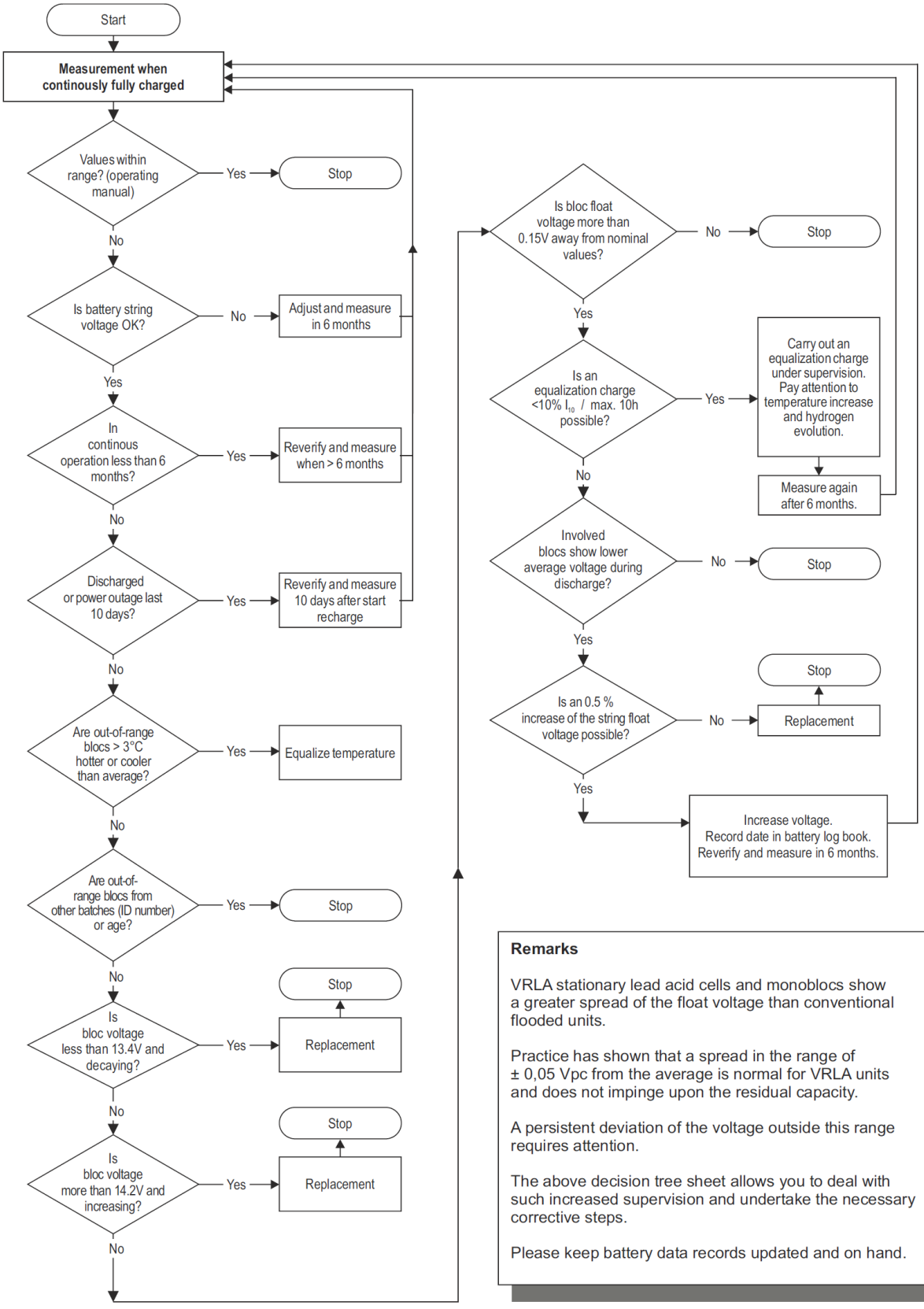
Title: Data sheet ZeMa*Rail* ZeMa340P12
File: Hawker_ZeMaRail_ZeMa340P12_Brochure_01_EN_2022-09-V1.pdf
4 pages, download from www.enersys.com

Appendix A5: Data sheet ZeMaRail ZeMa450P21

Title: Data sheet ZeMaRail ZeMa450P21
File: Hawker_ZeMaRail_ZeMa450P21_Brochure_01_EN_2017-12-V1.pdf
4 pages, download from www.enersys.com

Appendix A6: Decision tree for analysis of voltage deviations

(2V ZeMa*Rail* monoblocs and cells under continuous charge)



Remarks

VRLA stationary lead acid cells and monoblocs show a greater spread of the float voltage than conventional flooded units.

Practice has shown that a spread in the range of ± 0,05 Vpc from the average is normal for VRLA units and does not impinge upon the residual capacity.

A persistent deviation of the voltage outside this range requires attention.

The above decision tree sheet allows you to deal with such increased supervision and undertake the necessary corrective steps.

Please keep battery data records updated and on hand.

Appendix A7: Warning & Information signs on the tray