

Advanced Safety System for Advanced Battery Technology

Lithium batteries
Safety Aspects In Battery Packs

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MDEC 2019

Are Lithium batteries safe to use?

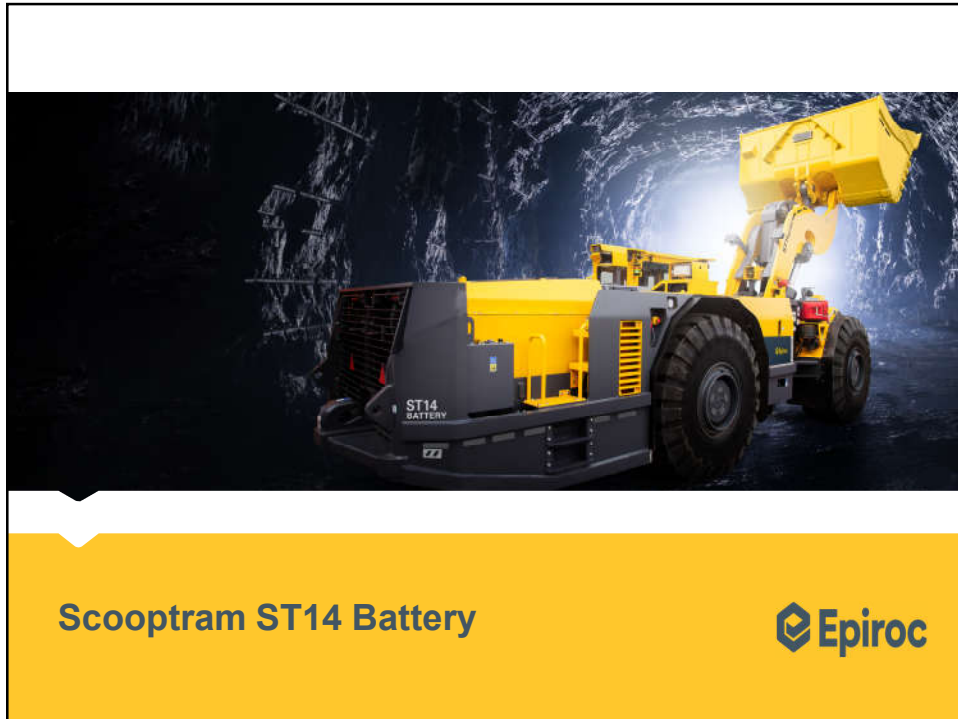
- Used daily by billions of people in many types of applications
 - Consumer electronic devices
 - Power tools
 - Medical devices
 - Automotive applications
 - Large-scale energy storage
- Statistical failure rate is low - The statistical failure rate of this technology is very low. The risk of failure is comparable to the same risk as getting struck by lightning during a lifetime - it is rare.
- The risk of a battery failure can be minimized by correct handling



Battery packs for underground mining

Second generation battery electric vehicles

Launched 2018



Boomer E2 Battery



7

Second Generation



Li-ion batteries

Epiroc's battery pack design



Minetruck MT42



Scooptram ST14



MLE Carrier

Northvolt battery system safety



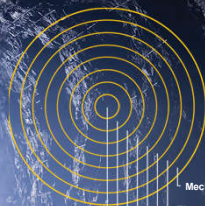
Pioneers

Breaking new ground: the Northvolt-Epiroc partnership continues

- Oscar Fors, President for Northvolt Battery Systems, says: "By meeting the highest functional and safety standards required by the demanding environment in an underground mine, we have developed a standard solution that can meet most industrial customer's needs as well."

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State of the art safety



Mechanical crash protection
Thermal Management System
System design and cell housing
Battery Management System
Battery disconnect (contactors)
Short-circuit protection (fuse)
Cell design and packaging
Cell chemistry

Protection against fire in battery cells

- Safe cell chemistry
- Small cells
- Cylindrical cells
- Fuse and overpressure vent in each cell
- All cells water cooled and thermally insulated
- Thermal insulation in several higher layers
- Three levels of Battery Management System (BMS)

Protection against fire from outside

- Fire suppression on machine and in battery pack

Electrical protection (battery and machine)

- HVIL – Never voltage with open connector or open cover
- Shielded cables
- Insulation monitoring
- Automatic and manual contactors, with health monitoring

Protection against rock-fall

- Thick top plate
- Cooling system as crash buffer
- Wire harness, hoses etc. as crash buffer

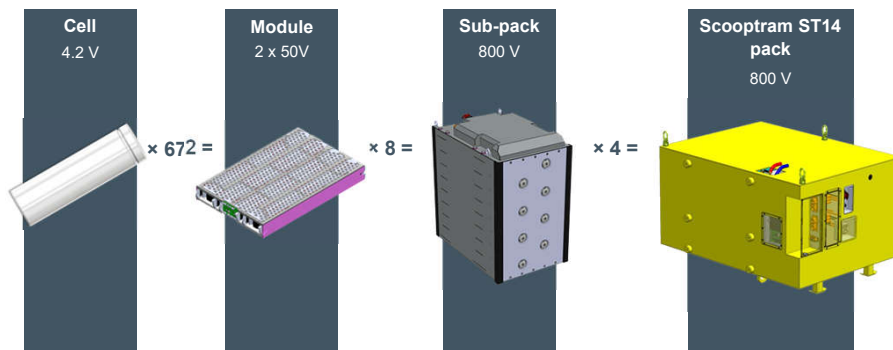
"Mine-proof"

- Thick steel casing
- Sealed (IP67) modules
- Condensation considered
- Designed for vibration level as machines
- Redundancy in battery modules Limp-home mode



Li-ion batteries

Battery building blocks for mining applications - From cell to pack

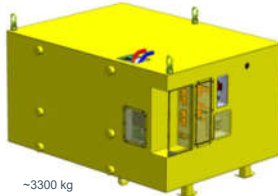


Battery Pack Configurations

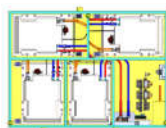
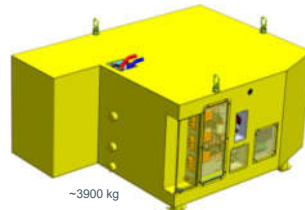
MLE - 2 sub-packs = 185 kWh



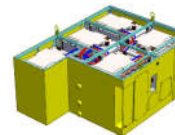
ST14 - 4 sub-packs = 365 kWh



MT42 - 5 sub-packs = 465 kWh

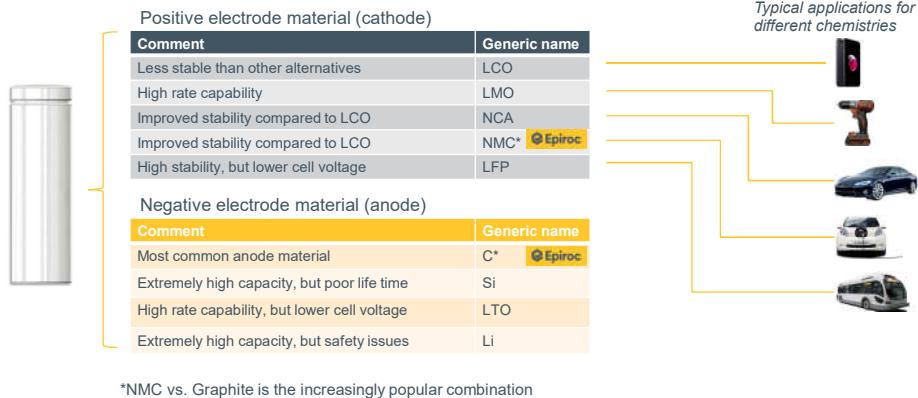


Cooling system
not included
in the pictures



Li-ion batteries

General design - Cell chemistries



*NMC vs. Graphite is the increasingly popular combination

Battery validation

- + Batteries are tested against severe abuse conditions in cell/module and pack level.
- + Passing these tests successfully defines battery safety performance. Typical pass criteria is no explosion or catching fire.

Cell level:

- + IEC 62133-2 or IEC 62660
- + UN 38.3, 6th ed. (Transportation tests)
- + UL 1642 (Standard for Safety for Lithium Batteries)

Battery system level:

- + IEC 61619 (Safety requirements for secondary Lithium cells and batteries, for use in industrial applications)
- + UL 2580 (Batteries for use in Electric Vehicles)

Table 1 – Sample size for type tests

Test	Cell ^{a, b}	Battery
7.2.1 Continuous charge	5	—
7.2.2 Case stress	—	1
7.2.3 External short-circuit	5 per temperature	—
7.2.4 External short-circuit	—	5
7.2.5 Free fall	5	3
7.2.6 Thermal abuse	5 per temperature	—
7.2.7 Crush	5 per temperature	—
7.2.8 Discharge	—	5
7.2.9 Forced discharge	5	—
7.2.10 Mechanical	—	3
7.2.11 Mechanical	—	3
7.2.12 Forced internal short ^{c, d}	5 per temperature	—
7.2.13 Measurement of the internal AC resistance for cells only	5	—

^a Excludes cells with an internal resistance greater than 50 mΩ.

^b Country specific test, only required for listed countries.

^c Not applicable to cells and lithium ion polymer cells.

^d For tests requiring charge procedure of 7.2.2 (procedure 2), 5 cells per temperature are tested.

→ TESTS FOR TECHNICIAN-REPLACEABLE AND USER-REPLACEABLE BATTERIES

• ELECTRICAL TESTS

• 10 Short-Circuit Test

• 11 Abnormal Charging Test

• 12 Forced-Discharge Test

• MECHANICAL TESTS

• 13 Crush Test

• 14 Impact Test

• 15 Shock Test

• 16 Vibration Test

• ENVIRONMENTAL TESTS

• 17 Heating Test

• 18 Temperature Cycling Test

• 19 Low Pressure (Altitude Simulation) Test

→ FIRE EXPOSURE TEST

• 20 Projectile Test

Fuses

Fuses breaks the current when the contactors cannot

Fuses on all system levels:

- Pack Fuses
- Sub-pack fuses
- Wirebond fuses on each cell in the module.
- The current Interrupt Disc inside cell breaks current in case of pressure build up.
- 24 volt control system has fuses.



Sub-pack and pack fuses



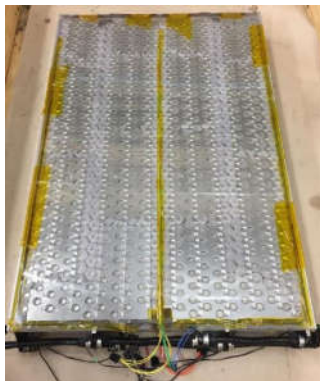
Current interrupted if pressure builds up



Cells connected via wirebonds

Module

672 cells, 12 kWh 2x44V, 50 kg



Fuses to each cell



Cooling channel



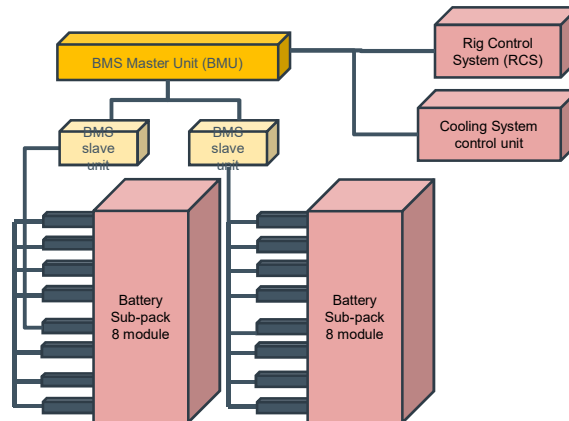
Battery Management System (BMS)

The brain and nerve system of the battery pack

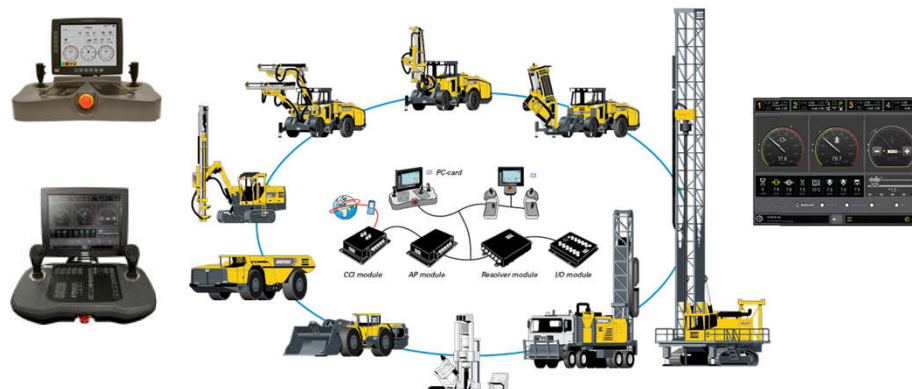
The BMS is an advanced control system that keeps the battery in a safe operation condition.

The BMS monitors:

- Voltage
- Current
- Temperature
- Other electrical safety functions



RIG CONTROL SYSTEM (RCS) ONE SYSTEM FOR ALL EPIROC PRODUCTS



A1

Contactors

- The 800 volt connections on sub-pack and pack have contactors.
- The contactors open in potentially unsafe scenarios.
- Examples of when contactors opens are:
 - Ground fault.
 - HVIL broken (next page).
 - Operation outside specified voltage, current, or temp. region.



Sub-pack
contactor



Pack
contactor

High Voltage Interlock Loop (HVIL)

Contactors open when dangerous voltage is accessible

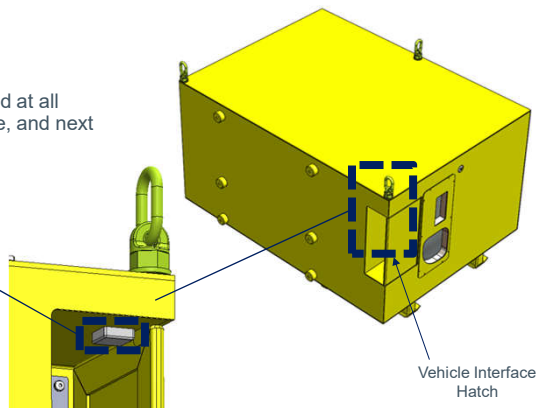
- HVIL is an electric control loop
- Contactors open if the loop is broken.
- Switches that opens the HVIL are located at all interface hatches and panels (see image, and next slide).
- 800 volt contacts also have built in HVIL
- 800 volt contacts are finger proof



HVIL on connections



This switch is pressed out when the hatch is opened, thereby opening the HVIL.



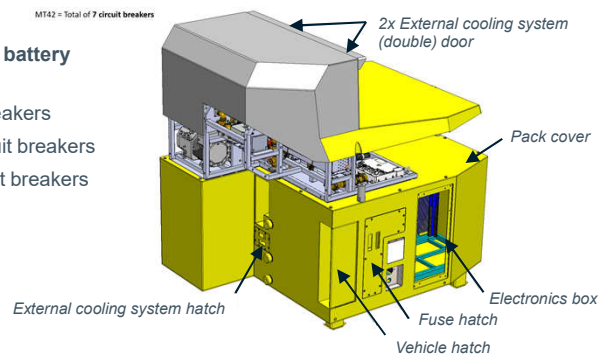
Vehicle Interface
Hatch

Contactors open when dangerous voltage is accessible

Hot zones protected by HVIL

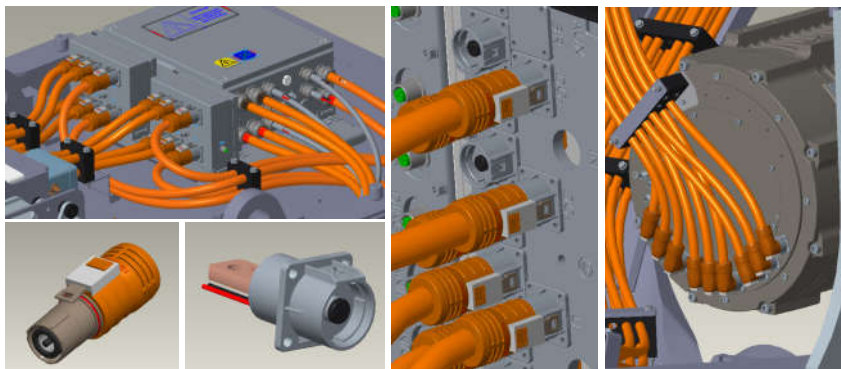
Number of HVIL in the different battery packs:

- **MLE Carrier:** 3 HVIL circuit breakers
- **Scooptram ST14:** 6 HVIL circuit breakers
- **Minetruck MT42:** 7 HVIL circuit breakers (highlighted in the image)



Overview of the HVIL protection in the MT42 battery pack

Amphenol power connectors

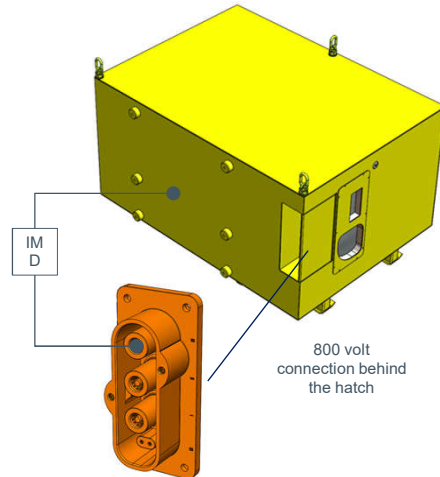


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Isolation Monitoring Device (IMD)

Protection from ground faults

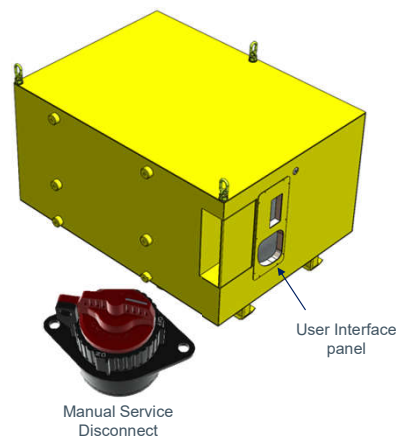
- The Isolation Monitoring Device (IMD) detects the resistance between:
 - Plus (+) and chassis
 - Minus (-) and chassis
- Ground fault is detected by a low resistance.
- In case of ground fault the contactors opens and operators and service personal are protected from dangerous voltages.



Manual Service Disconnect

An extra layer of safety during service

- A manual service disconnect (MSD) is located on the user interface panel (see image)
- Shall be put in its off position during service.
- Contactors are maintained open when MSD is, protecting personnel from dangerous voltages.
- By accessing the service panel, the HVIL is broken and contactors are open. The MSD adds an additional safety layer, making it impossible to accidentally close the contactors during service.
- 800 volt machine cables shall be locked on the machine as an additional safety precaution.
- An active discharge circuit discharge any dangerous voltage on the machine side.



Thermal management system

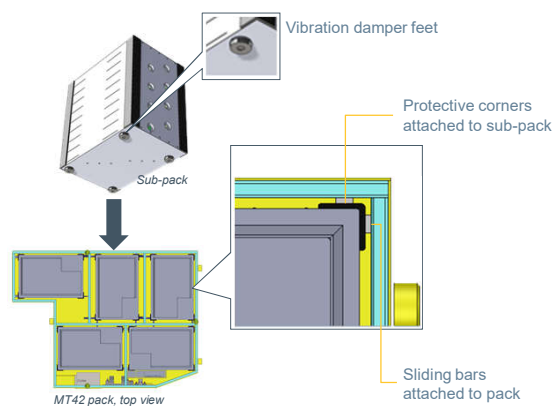
- MH built on top of the battery
- Drilling integrated into the battery
- Ensures batteries are working at optimal temperature range
 - Cooling or warming up
 - On the vehicle and while charging
- Utilization temperature range
 - Approved T 0 – 40°C
 - Optimal ambient T 15 – 25°C
 - Optimal battery T 20 – 30°C
- Charging preferably at cooler temperatures
 - Optimal cell temperature 10 – 30°C
 - Never below 0°C



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Enclosure and mechanical protection

- The pack enclosure are made of thick steel plates that protect from mechanical impact
- A frame keeps sub-packs in place inside the pack.
- Protective corners protect the sub-packs mechanically
- The sub-packs have vibration dampening feet.

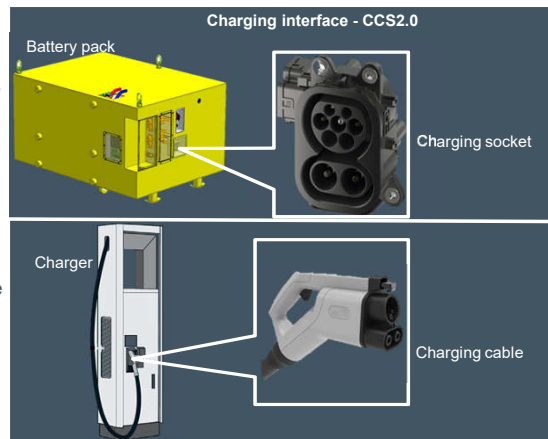


The charging interface

Socket and cable, Scooptram ST14, Minetruck MT42 and MLE Carrier

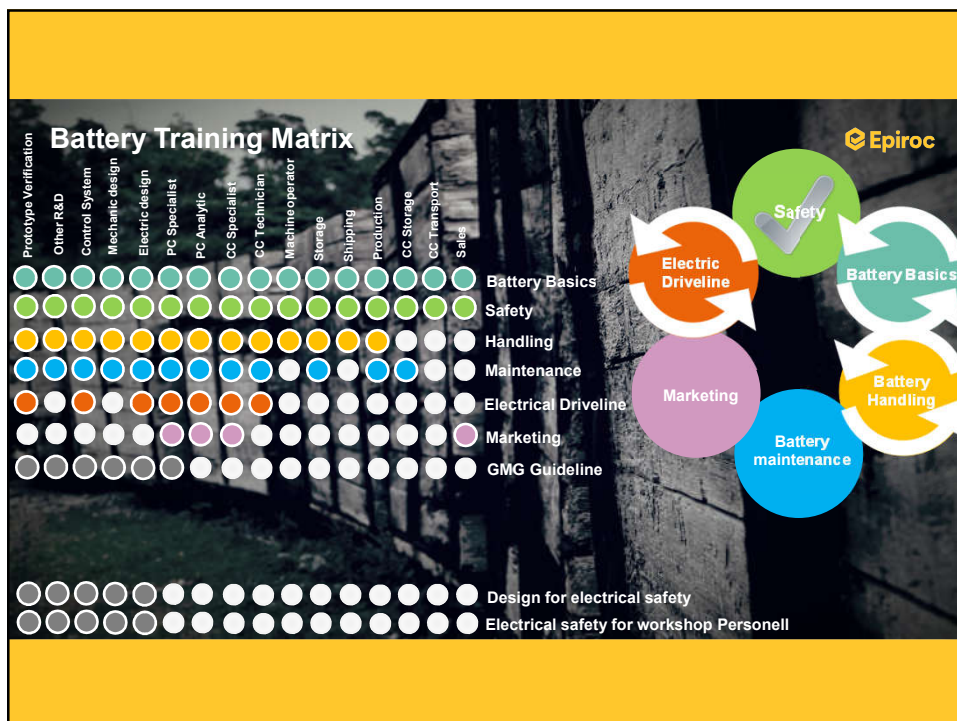
Charging interface features:

- Charging socket and charging cable are finger proofed
- The socket and cable are energized only when connected
- Charging socket is protected by a temperature sensor monitored by the BMS
- Charging cannot be initiated if the vehicle is still running
- During charging the cooling system will be activated



Instant seamless technology leap – pay per use





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