Journey to a New Regulatory Option

Internal Short Detection/Thermal Runaway Prevention

OICA Submission to IWG for GTR 20, Phase 2

Jan 2021 – IWG #20, Virtual meeting

Outline

Part 1:	The Journey
Part 2:	Update on Research Activities
Part 3:	Examples for Commercial Solutions
Part 4:	Proposal for New Regulatory Text

Part 1:
The Journey

Journey to a New Regulatory Option

Internal Short Detection/Thermal Runaway Prevention

- Introduce concept that detection is possible – COMPLETE
  - IWG meeting #15, Beijing (March 2018)
  - EVS1536-613
- Describe scientific basis for safe/unsafe zones and analysis methods to support development – COMPLETE
  - IWG meeting #18, Tokyo (June 2019)
  - EVS18-E1TP-0400
- Provide examples of how internal shorts can be detected, including potential alternative methods – COMPLETE
  - IWG meeting #19 (December 2019)
  - EVS19-E1TP-0300
- Provide examples of commercial development of approaches for internal short detection ***(new step)***
  - IWG meeting #20 (Jan 2021)
- Develop conceptual regulatory text ***(changed sequence)***
  - IWG meeting #20 (Jan 2021)
- Describe acceptable risk concepts and levels – How good does detect/prevent need to be?
  - Mid to late of 2021 *(revised date)*
- Demonstrate successful detection and benefit when detection occurs
  - TBD *(revised date)*

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KEY MESSAGE:
Under some circumstances internal shorts are detectable. This detection may provide opporunity to take action. Thereby completely preventing thermal progation

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KEY MESSAGE:
Scientific principles can be used to explain thermal runaway behavior, including how it is possible to have an internal short circuit without thermal runaway.

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KEY MESSAGE:
Since thermal runaway is a mechanical/thermal/electrochemical phenomenon, characteristics and behaviors associated with Li ion cell thermal runaway can be detected, in some cases prior to onset of thermal runaway

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KEY MESSAGE:
Commercially and technically viable approached for early detection of potential internal short circuits are currently under development for automotive applications.

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KEY MESSAGE:
A regulatory framework which enables application of early detection technologies is possible with minimal changes to GTR 20 content.

Part 2:
Update on Research Activities

Ongoing research (ACEA)

Thermal runaway and thermal propagation detection in collaboration with Horiba-MIRA (ultrasonic) and EFZN (observation model)

- ➢ 2019 – Thermal runaway detection methods
  - ✓ Desktop study of published reports (scientific journals)
  - ✓ Different technology approaches and detection principles
  - ✓ Real world implications for BMS detection methods
- ➢ 2019 – Proof of concept
  - ✓ Ultrasonic detection
  - ✓ Electro-thermal observation model (voltage and temperature)
- ➢ 2020 – Experimental development of detection methods
  - ✓ Feasibility on aggregated level, minimum cell stack configuration.
  - ✓ Specificity for internal short circuit detection
  - ✓ Detection accuracy and risk of false positives

Presented in Berlin 2019

Ultrasonic detection 1/2

The study showed that even small cell defects cause significant changes in the accoustic signal

- ➢Parallel CT scanning as an independent non-destructive method to detect cell defects

The internal temperature of a given cell can be measured since there is a linear relationship between internal cell temperature and time of flight of the first echo peak was demonstrated for a pouch cell in mildly abusive conditions (-10 to 60 °C)

Main advantages:

- ➢Non-destructive
- ➢Can be performed in operando
- ➢Relatively cheap
- ➢Fast - measurements take only microseconds to complete
- ➢Can be used to probe any type of battery - transducer frequency, choice of pulse-echo or transmission transduces and relative placement need to be optimized for the cell type and dimensions

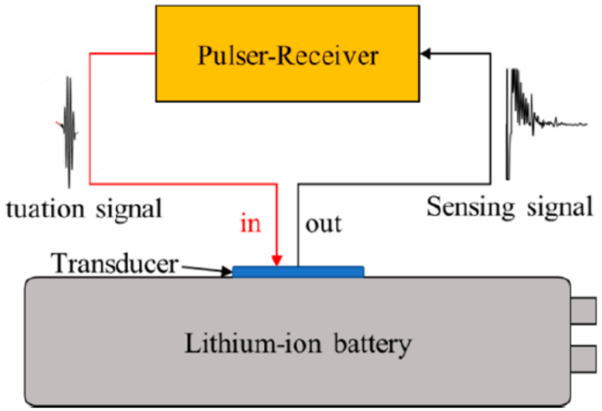


Figure 1: pulse-echo mode setup [23]

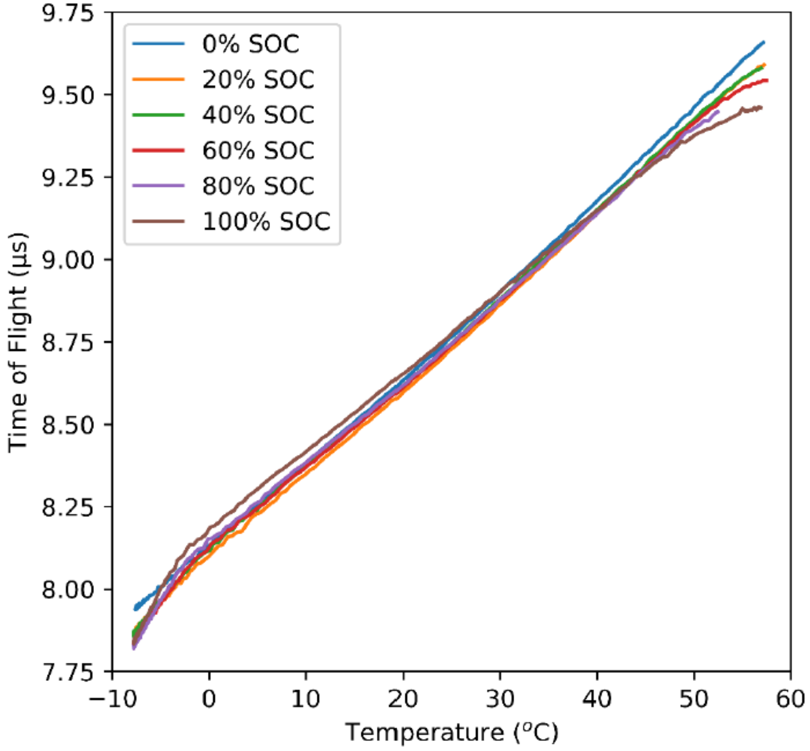


Figure 5: The variation of time of flight of the first echo peak at various states of charge.

Ultrasonic detection 2/2

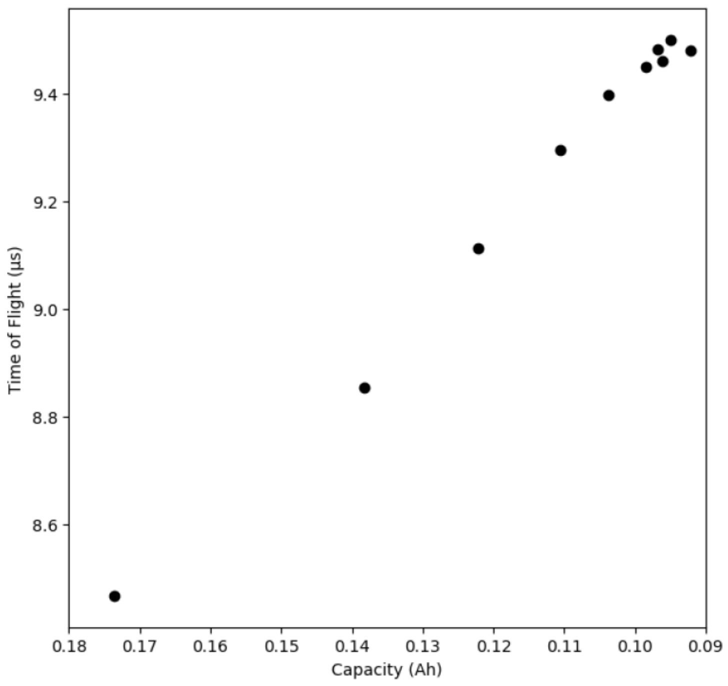


Figure 9 A plot showing the variation in the time of flight of the 'first echo' peak with cell capacity fade

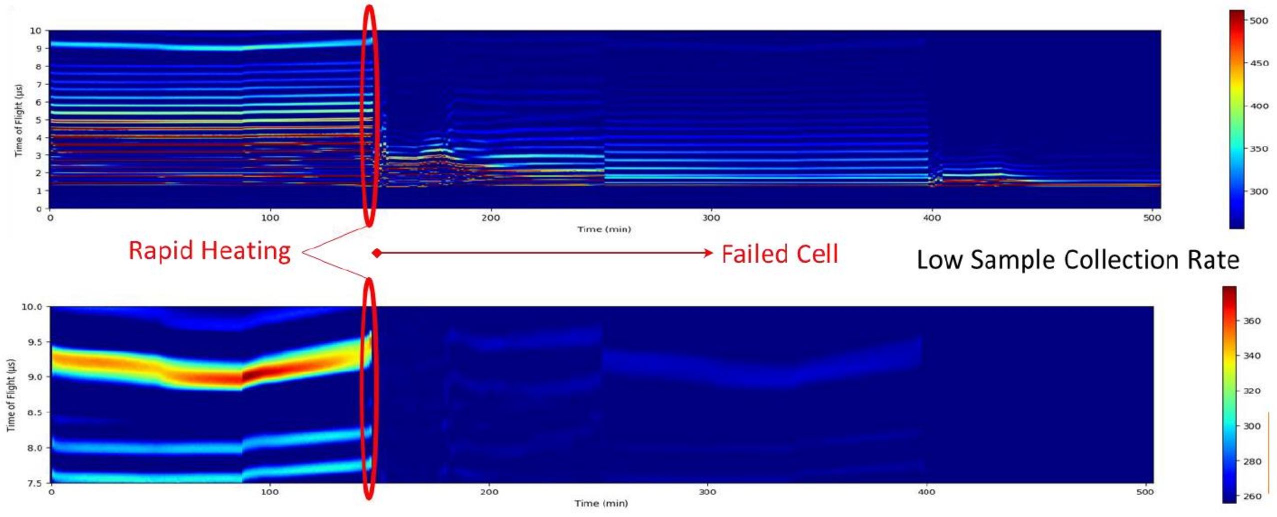


Figure 8: colourmap plots of the acoustic signal (a) and first echo peak (b) during the final charge –discharge step followed by rapid heating and cell failure

Linear relationship between time of flight and capacity, which means that the SOH can be measured accurately as long as it is measured at the same SOC in ageing cells experiencing capacity fade.

Spontaneous failure of 210 mAh pouch cell during long-term cycling. Initially, a small flight time deviation (5 oC temperature raise) followed by a very rapid raise as the whole cell fails.
Small deviations in the linear relationship between time of flight and temperature can be used to detect even minor cell damage. Additionally, capacity loss caused by gas evolution is also detectable.

Electro-thermal observation model 1/2

Principle of detection:

- ➢Any cell fault will lead to temperature increase

⇒Fault detection by

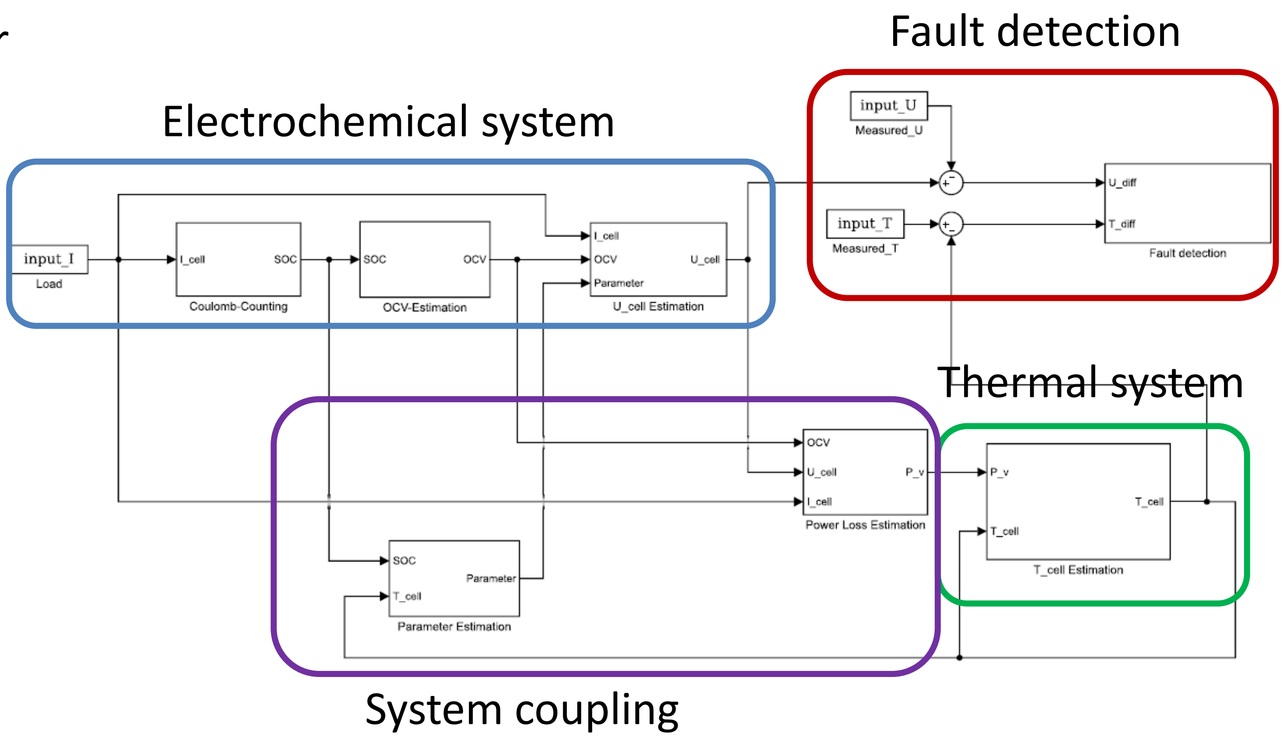
- ➢Identification of abnormal temperature behavior
- ➢Change in electrochemical response
- ➢Detailed model is needed

Main advantages:

- ➢Does not require additional sensors to those already in place
- ➢Pure software solution – customized to specific battery design thru model parameterization
- ➢Small changes in cell behavior can be detected – possibility for early fault detection

Disadvantages:

- ➢Misdetection/false negatives
- ➢Parameterization and adaption of model



Electro-thermal observation model 2/2

Experimental verification:

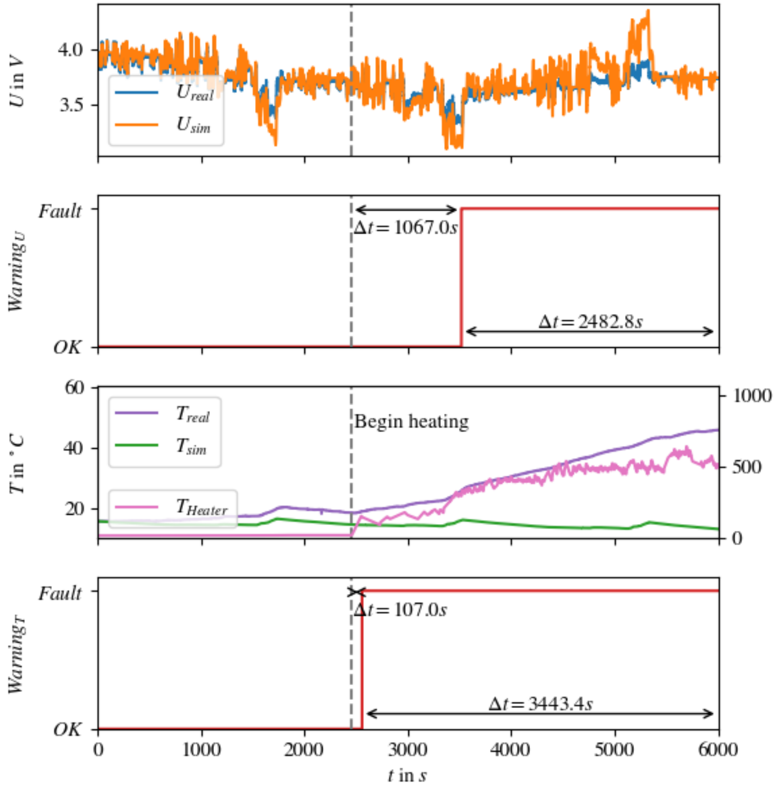
- Thermal pulse test
- Fault induction (external heating)
  - ✓2x200W heat cartridges (local)
  - ✓2x700W heater elements (uniform)
- WLTP cycle to simulate load

Further investigation into applicability required

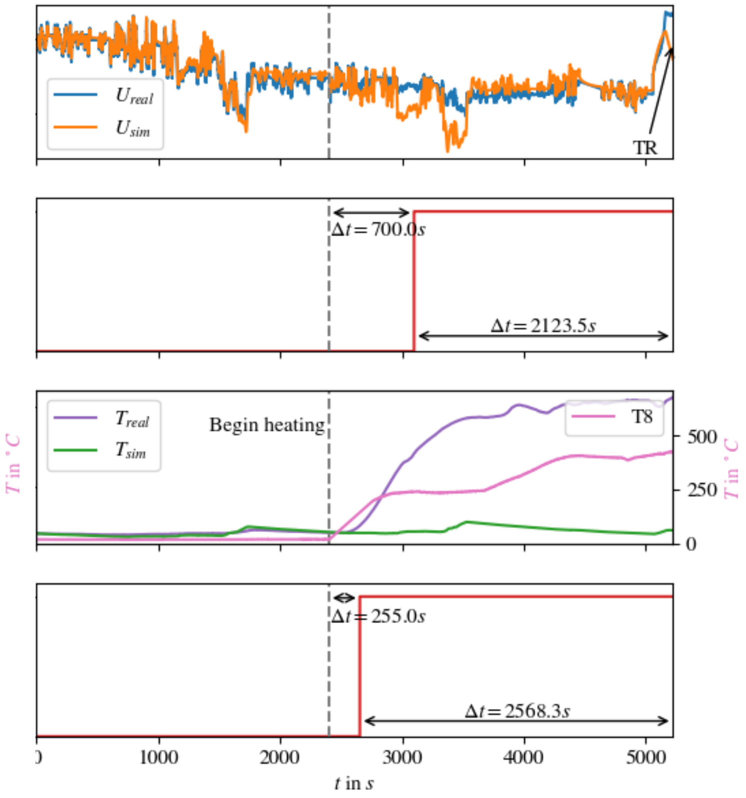
- Changing environmental conditions
- Cell/battery assemblies

Solution for changing cell parameters needed

Local heating



Uniform heating



46 Ah Kokam Nano cells

Part 3:
Examples for Commercial Solutions

List of companies and institutions that are developing thermal runaway and thermal propagation early detection systems (not exhaustive)

Company	Location	Web Page	Specialty
Batemo	Karlsruhe, Germany	www.batemo.de	Modelling
CIDETEC Energy Storage	San Sebastián/Donostia, Spain	www.cidetec.es	Modelling
Titan Advanced Energy Solutions	Somerville, MA, U.S.A.	www.titanaes.com	Ultrasound
CAMX Power	Lexington, MA, U.S.A.	www.camxpower.com	Short detection and monitoring product
Fraunhofer Institute for Silicate Research ISC	Würzburg, Germany	www.isc.fraunhofer.de	Ultrasound
ISEA, RWTH Aachen University	Aachen, Germany	www.isea.rwth-aachen.de	Ultrasound and Impedance Spectroscopy
Nanyang Technological University (NTU Singapore) und KVI Battery	Singapore, Singapore	www.ntuitive.sg	Battery Enthalpy and Entropy Measurements

BATEMO CELLS

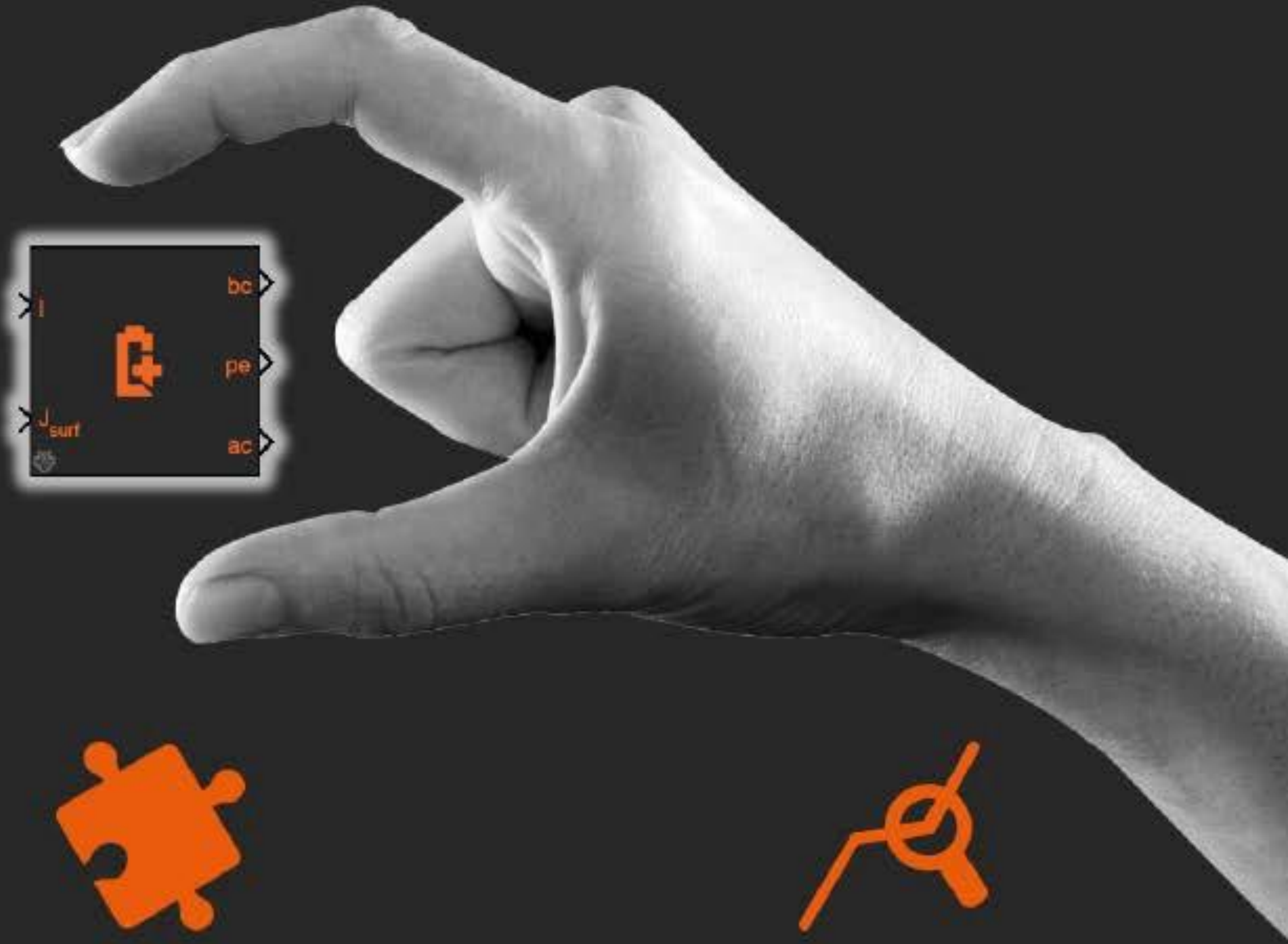
Early Detection of Thermal Propagation

DR.-ING. JAN RICHTER

VISION

EARLY AND RELIABLE DETECTION OF THERMAL PROPAGATION BY PRECISE PHYSICAL MODELS

BATEMO CELLS



strictly physical cell model

precise models of anode, cathode and electrolyte
accurate description of all relevant cell processes
allows arbitrary simulations including faults and extrapolation

customer-specific parameterization

available as a service for all cell types and lithium ion chemistries
includes parameterization and extensive validation
fast (about 6 weeks)

proven validity

all temperatures (-20°C to 80°C)
all SOCs (0% to 100)
all currents (30C and more)

Application in Thermal Prograpation

ELECTRO-CHEMICAL

coupled

simulation of critical quantities for thermal propagation

- terminal voltage V and $\frac{dV}{dt}$
- anode and cathode surface potentials V_{an} and V_{ca}
- consideration of aging effects
- simulation of faults under all operational conditions

THERMAL

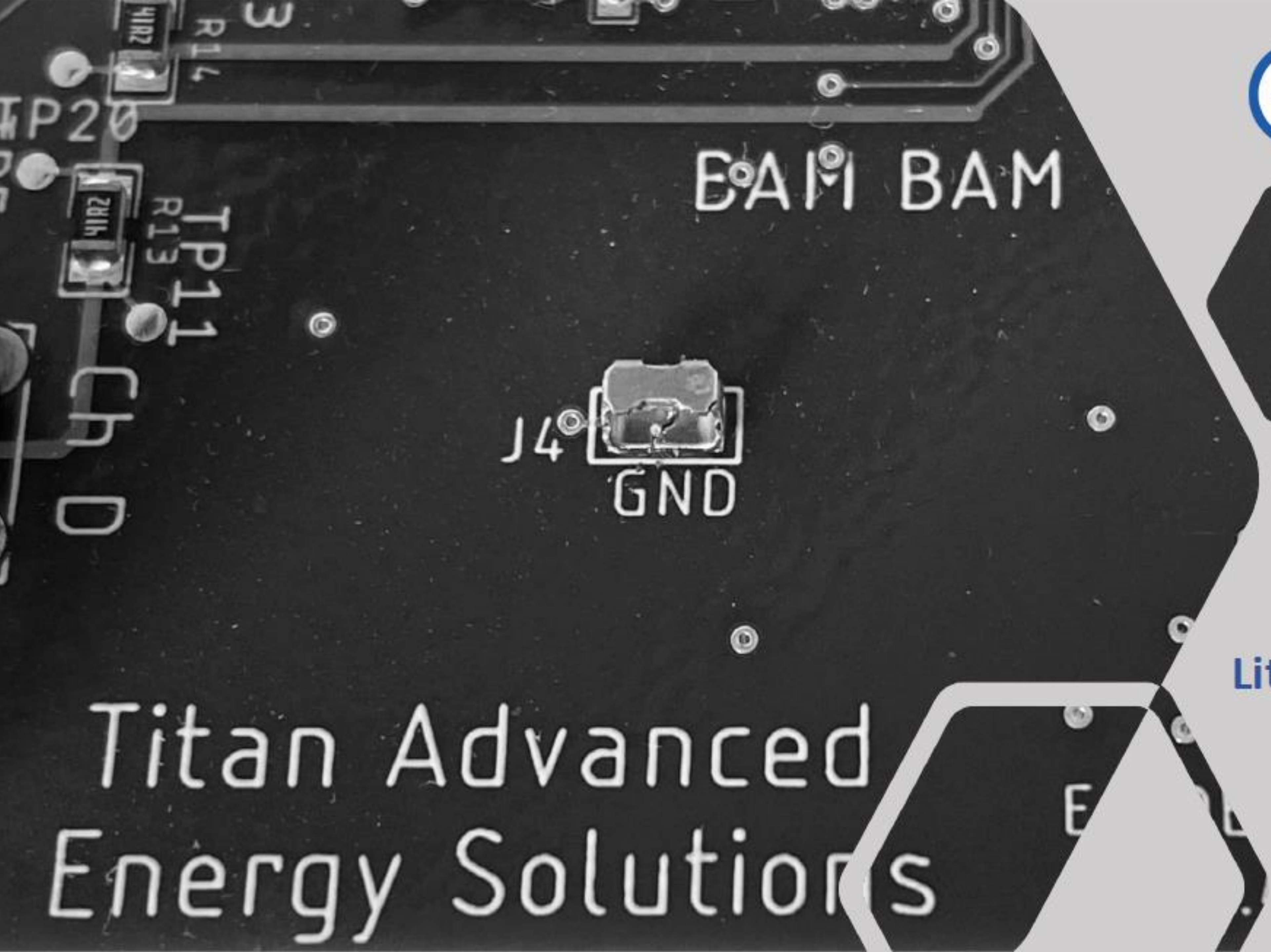
simulation of thermal behavior and heat exchange

- thermal model that calculates inner and surface temperatures T and $\frac{dT}{dt}$

perfect commercial tool for **development** and **validation** of **early detection algorithms** of thermal propagation (SIL / HIL / PHIL)

Batemo GmbH

- founded in **March 2017**
- **100% self-financed** and independent
- operation of own battery lab: **chemical lab** with equipment for cell opening and analysis and **electrical lab** for characterization (-40°C to 80°C with terminal currents of up to 720A)
- active in **various markets**: customers come from power tools, light mobility, automotive, industrial and cell manufacturing sectors



TITAN
ADVANCED ENERGY SOLUTIONS

Safety System for Lithium-ion Batteries

January 2021

WHAT

Our technology dramatically improves the economics and performance of Li-ion batteries, increasing their usable capacity, doubling their lifetime, and providing unprecedented safety

HOW

Our ultrasound-based technology measures the molecular and physical states of the battery in real-time yielding high accuracy state-of-charge(SoC) and state-of-health (SoH) measurements.

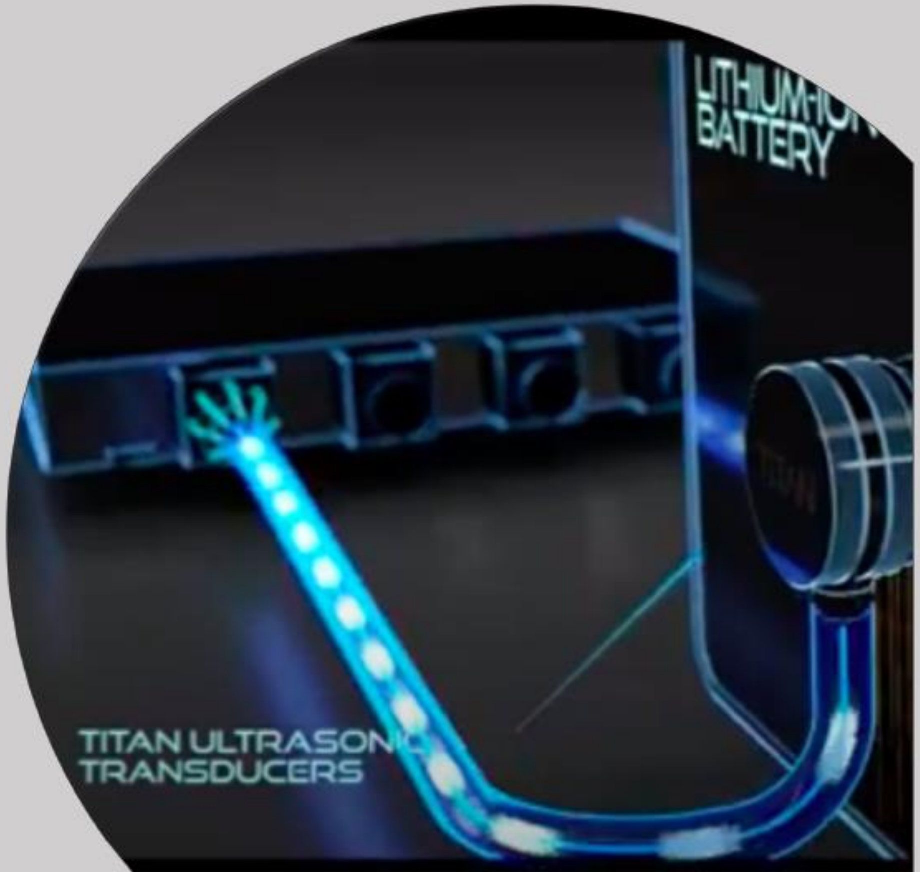
Note: Unlike incumbent open-loop systems that rely on SoC & SoH estimates, our technology is the first to observe and measure these variables using ultrasound. (Big deal)

TITAN Technology Description

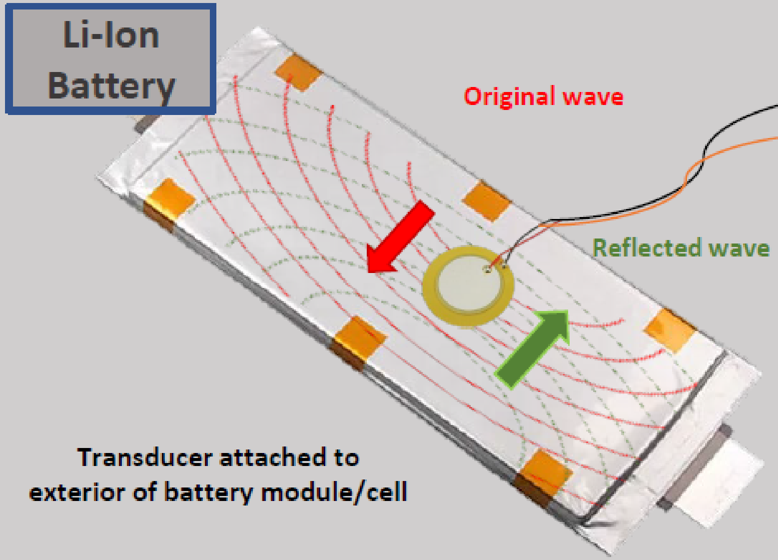
TITAN's **enhanced Battery Management System (eBMS)** combines ultrasonic sensing, proprietary electronics, and advanced algorithms to improve the performance of incumbent BMS, increase capacity and lifetime, and provide unprecedented safety monitoring

How TITAN's system works:

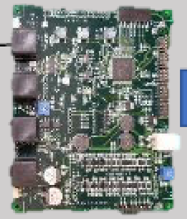
- Ultrasound technology is used to perform a real-time molecular scan within the battery pack to provide accurate information on the physical state of its components (EV cells and modules).
- The ultrasonic signal is processed in real-time using advanced algorithms and machines learning techniques to provide SoC and SoH measurements with 99% accuracy.
- By integrating TITAN's technology, BMS can detect even slight deviations from normal values of descriptive properties (cell level) and/or the appearance of abnormal features in the scans enabling early detection of abnormal and dangerous battery states.



Implementation: TITAN's Ultrasound *e*BMS – Technical Overview

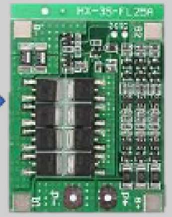


Transducer attached to exterior of battery module/cell



TITAN EchOES™

SoH / SoC



Legacy 3rd Party BMS

BMS data

Real-time molecular ultrasonic scan, enabling direct determination of the actual State-of-Health and State-of-Charge with consistent 99% accuracy.

Titan SoH:

System focuses on:

- The secondary solid electrolyte interface (SSEI) growth over time, which changes the mechanical structure of the anode
- Measuring SoH by monitoring structural changes via ultrasound

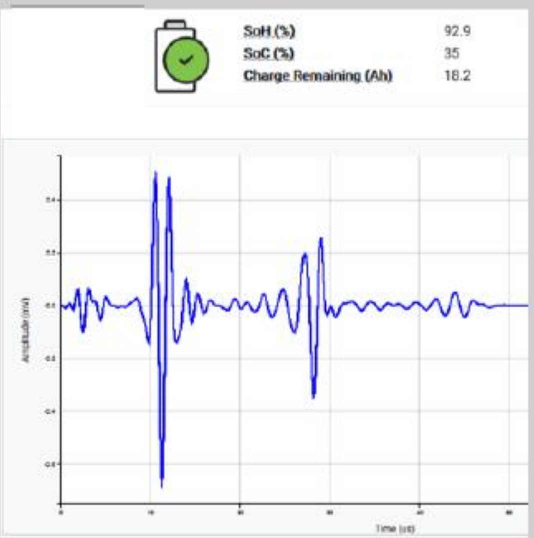
Titan SoC:

System focuses on:

- Battery charging (Lithium-Ion intercalation) increases anode stiffness
- Measuring SoC by monitoring stiffness change via ultrasound

Real EV Outgassing Example – Evaluated Cells (Tier 1 OEM)

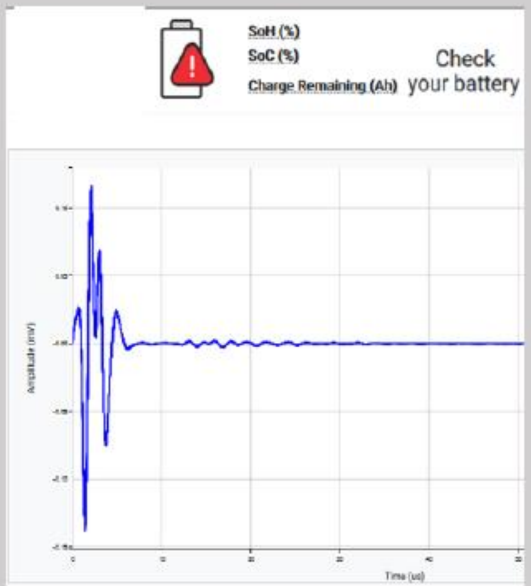
Ultrasonic Signal in a healthy battery



Normal

Visible gas bubbles on the exterior of the cell

Ultrasonic Signal in an outgassed battery



With Gassing

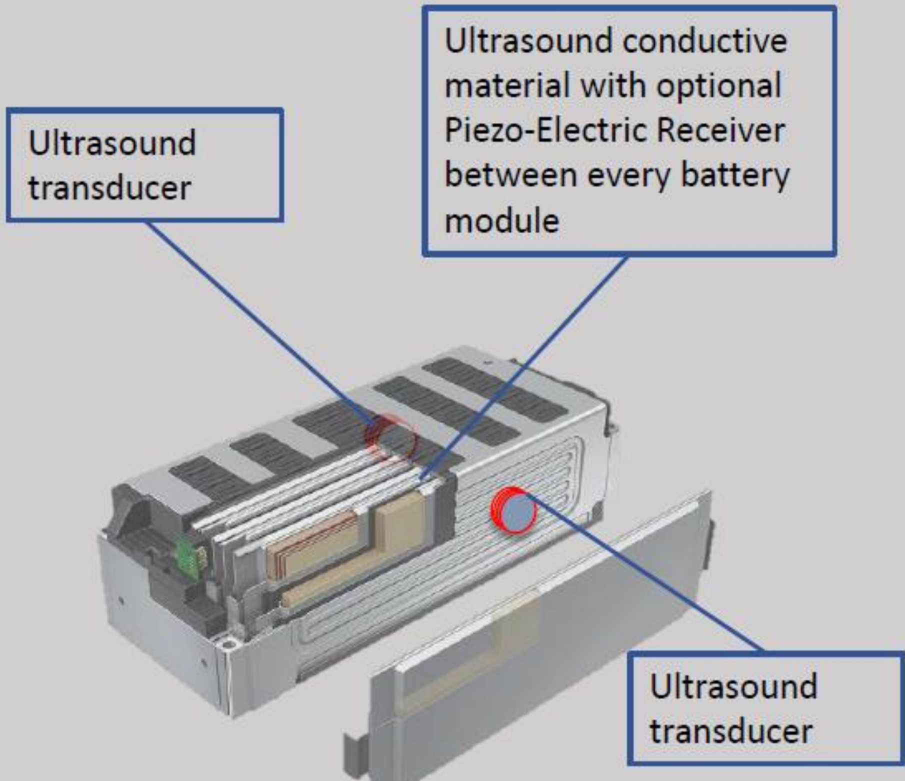
Why TITAN's eBMS?

TITAN's pioneering technology works with incumbent systems to improve the performance, safety, and economics of lithium-ion battery systems by:

1. Delivering unprecedented safety through early detection (50-100 cycles before conventional BMS systems) on multiple failure mechanisms (gas, thermal, electrical) through closed-loop, real-time monitoring

2. Increasing battery capacity (+20%) due to high 99% accuracy, real-time SoC/SoH and the reduction of unnecessary safety buffers

3. Extending battery life (cycles) by using a real time SoH measurement vs. look up table (2X) which optimizes charging/discharging cycles



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Part 4:
Proposal for New Regulatory Text

Rationale for proposing changes to the present GTR 20 text

Basic concept:

OICA is convinced that any kind of mandatory trigger-based thermal propagation test – however it might look like at the end – will lead to a certain level of design restrictions and measures that will be needed to fulfil the test although they do not provide any additional safety benefit for the customers and their surroundings.

Therefore, OICA asks for an additional OEM option, namely to be able to choose either to use the mandatory thermal propagation test or to provide an early detection system for thermal propagation including the demonstration of its appropriateness, viability and suitable performance.

Therefore, the regulatory GTR 20 text with respect to the documented approach should be modified to account for this further option.

The proposed changes are also useful because they give a clearer picture on the documented approach including experiments and/or simulation that support it.

Proposed changes to section 5.4.12.2. :

5.4.12.2.

The vehicle shall have functions or characteristics in the cell, REESS or vehicle intended to protect vehicle occupants (as described in paragraph 5.4.12.) in conditions caused by thermal propagation which is triggered by an internal short circuit leading to a single cell thermal runaway. At the choice of the manufacturer, these characteristics can be predictive or reactive or a combination of both. Vehicle manufacturers shall make available, at the request of the regulatory or testing entity as applicable with its necessity, the following documentation [explaining safety performance of the system level or sub-system level of the vehicle] (see also paragraph 196 in Part 1, section E).

Proposed changes to section 5.4.12.2.1. :

5.4.12.2.1.

A risk reduction analysis using appropriate industry standard methodology (for example, IEC 61508, MIL-STD 882E, ISO 26262, [GB/TXXX], AIAG DFMEA, fault analysis as in SAE J2929, or similar), which documents the risk to vehicle occupants caused by thermal propagation which is triggered by an internal short circuit leading to a single cell thermal runaway and documents the reduction of risk resulting from implementation of the identified risk mitigation functions or characteristics. Risk mitigation functions or characteristics in this context also mean detection functions or characteristics that act early enough to prevent the event of a thermal runaway or thermal propagation to occur. This is because the warning is triggered early enough to allow controlled removal, repair or replacement of affected parts or their components before a serious thermal event can take place.