Contents of Work Package 3-WP03 Batteries: Solutions for Testing and Modeling

3-WP03: Batteries: Solutions for Testing and Modeling

Coordinator of the WP

Czech Technical University in Prague, MSc. Václav Knap, Ph.D.

Participants of the WP

ŠKODA AUTO a. s., Garrett Motion Inc.

Main Goal of the WP

Advancement of battery technology aspects to provide additional value to battery-based automotive vehicles, to improve their design processes, to reduce the development cost, and to provide diagnostic capabilities. Selected tools for achieving these goals are a battery modeling platform and a quick battery diagnostic technique.

Partial Goals for the Current Period

Partial goals for the current period were to prepare and start up laboratory testing of batteries which will be used for model parametrizations and develop a HW setup that will allow for accurate electrochemical impedance spectroscopy measurements.

Contents of Work Package 3-WP03 Batteries: Solutions for Testing and Modeling

3-WP03: Batteries: Solutions for Testing and Modeling

Official 3-WP03 Deliverables:

- 3-WP03-001 | **Complex traction battery model**, R, XII./2025, CTU 0.9; GM 0.1
- 3-WP03-002 | **Device and setup for quick diagnostic of automotive batteries**, G-funk, XII./2025, CTU 0.9; GM 0.1
- 3-WP03-003 | **Report on Milestones - Battery electric vehicle optimizer using complex traction battery model – results description**, O, XII./2025, CTU 0.9; GM 0.1
- 3-WP03-004 | **Report on Milestones - Quick diagnostic for automotive batteries via impedance measurements – results description**, O, XII./2025, CTU 0.9; GM 0.1

Team of Work Package 3-WP03 Batteries: Solutions for Testing and Modeling

CTU in Prague, FEE (CTU FEE)

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- Rastislav Toman

ŠKODA AUTO a.s. (SA)

- Catherine Lee Oppenheimer
- Anna Pražanová

Garrett Motion Inc. (GM)

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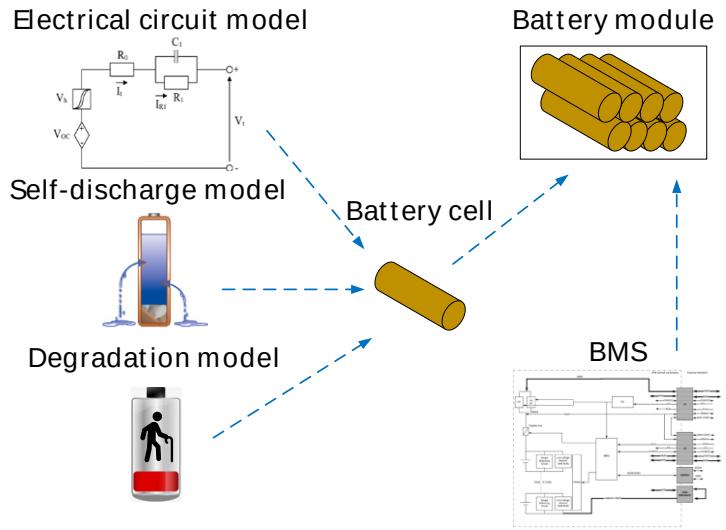
Activities in 3-WP03 Batteries: Solutions for Testing and Modeling

3-WP03-001: Complex traction battery model

- Model for simulating a battery pack for automotive.
- Based on equivalent electrical circuit models of battery cells, including the dependence of its parameters on state-of-charge, temperature, and state-of-health.
- It will cover various cell chemistries.
- It will enable benchmarking of various state estimation algorithms.
- It will support design optimization with the remaining parts of a vehicle.

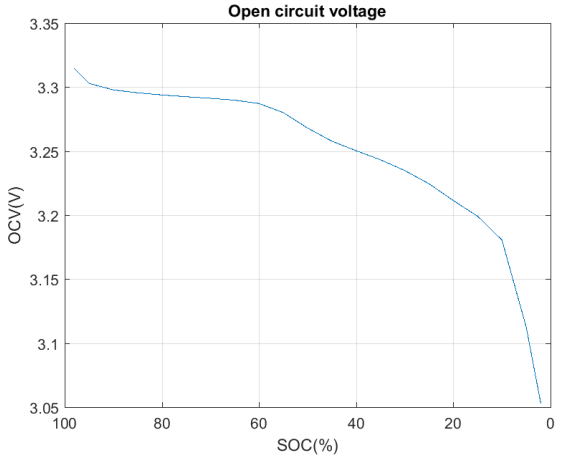


Activities in 3-WP03 Batteries: Solutions for Testing and Modeling

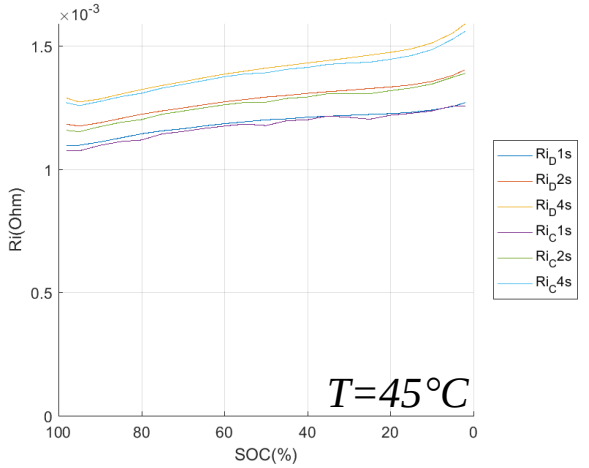
3-WP03-001: Complex traction battery model

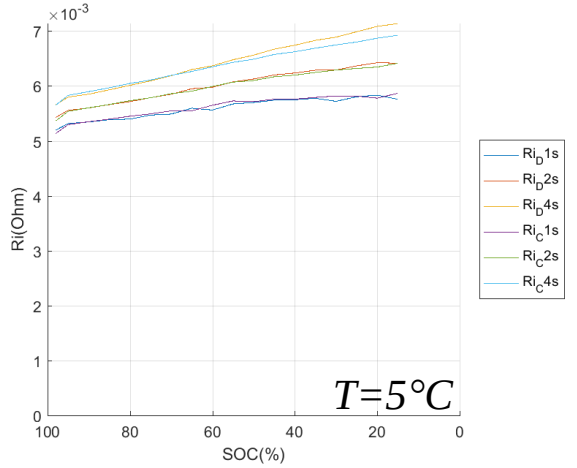
Preliminary characterization test activities:

- Experiments with aged LFP 90 Ah (49 Ah actual) cell leading to OCV (SOC) and R_i (t, SOC, ϑ) curves results.



Winston LFP 90 Ah cell





Activities in 3-WP03 Batteries: Solutions for Testing and Modeling

3-WP03-001: Complex traction battery model

- Identified battery cells for testing.
- Identified necessary test procedures.

Selected test procedures

Characterization

Order	Test
1	Pre-conditioning test
2	Open-circuit voltage test
3	Pulse test
4	Capacity test
5	Dynamic discharge profile test
6	Driving profile test
7	Hysteresis test
8	Kinetic battery model characterization test
9	Entropy heat coefficient test
10	Heat generation test

Aging

Order	Test
1	Pre-conditioning test
2	Reference performance test
3	Degradation test (cycling or calendar)
4	Repeating tests 2 and 3 until selected treshold

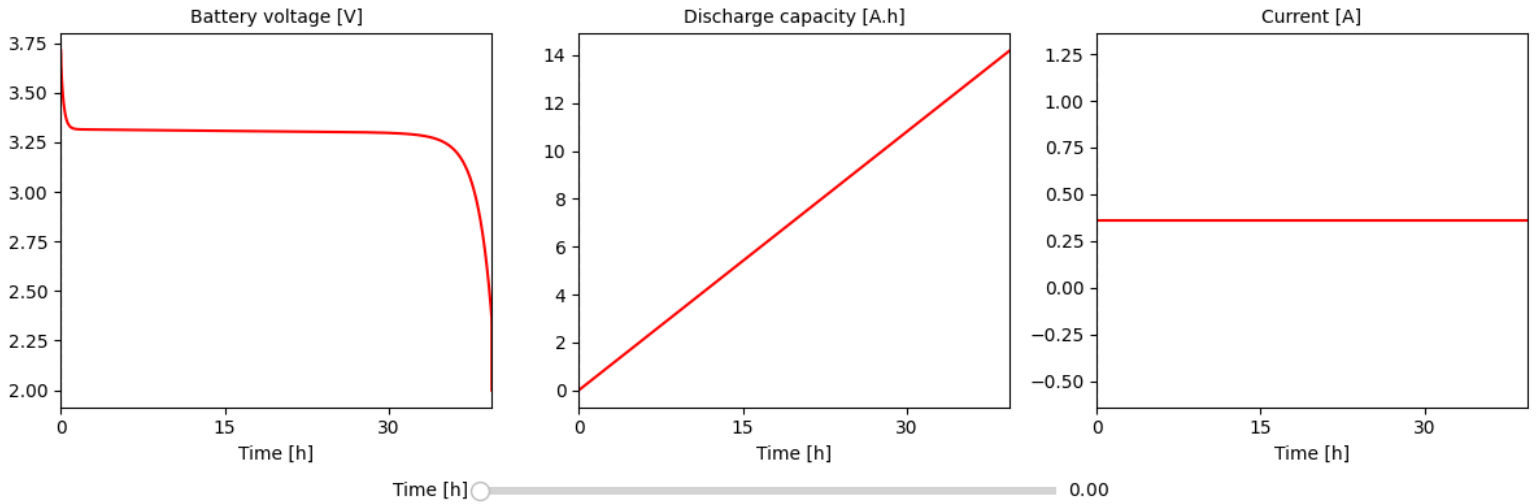
Selected cells

Manufacturer /supplier	Composition	Format	Capacity
Panasonic	NCA / G	Cylindrical	3.25 Ah
LG	NMC / G+Si	Cylindrical	3.5 Ah
JGNE	LFP / G	Cylindrical	1.8 Ah
GWL	? / LTO	Cylindrical	1.3 Ah
LG	TBD	Pouch/pris-matic	TBD

Activities in 3-WP03 Batteries: Solutions for Testing and Modeling

3-WP03-001: Complex traction battery model

- Assessing "Python Battery Mathematical Modelling" (PyBaMM) toolbox to enhance the modelling approach.
- LFP/Graphite Li-ion battery cell implemented in PyBaMM as a Doyle-Fuller-Newman model (so-called pseudo-2D model) with parameter values based on previous calibration performed in GT-AutoLion within the project TN01000026 "Josef Bozek National Center of Competence for Surface Vehicles".



Activities in 3-WP03 Batteries: Solutions for Testing and Modeling

3-WP03-002: Device and setup for quick diagnostic of automotive batteries

- Measurement setup for quick diagnostic of automotive batteries based on impedance characteristics, including measurement, data processing, and result interpretation.
- The technique is based on electrochemical impedance spectroscopy analysis.
- It aims to be applicable for battery evaluation, production quality control, and battery sorting for a second life.
- The proposed technique will provide extensively more insight into battery electrochemical parameters than classical charge-discharge tests assessing only capacity and 'simple' resistance.
- It will be significantly quicker and cheaper than laboratory-grade electrochemical impedance spectroscopy measurements. Thus, it shall enable higher quality products (increased reliability, lifetime) and significantly improve its economy (faster measurement time, cheaper investment cost).

Activities in 3-WP03 Batteries: Solutions for Testing and Modeling

3-WP03-002: Device and setup for quick diagnostic of automotive batteries

- Review of electrochemical impedance spectroscopy techniques.
- Identified various approaches, however difficult to objectively compare due to heterogenous conditions.
- Current focus on single sinusoidal method.

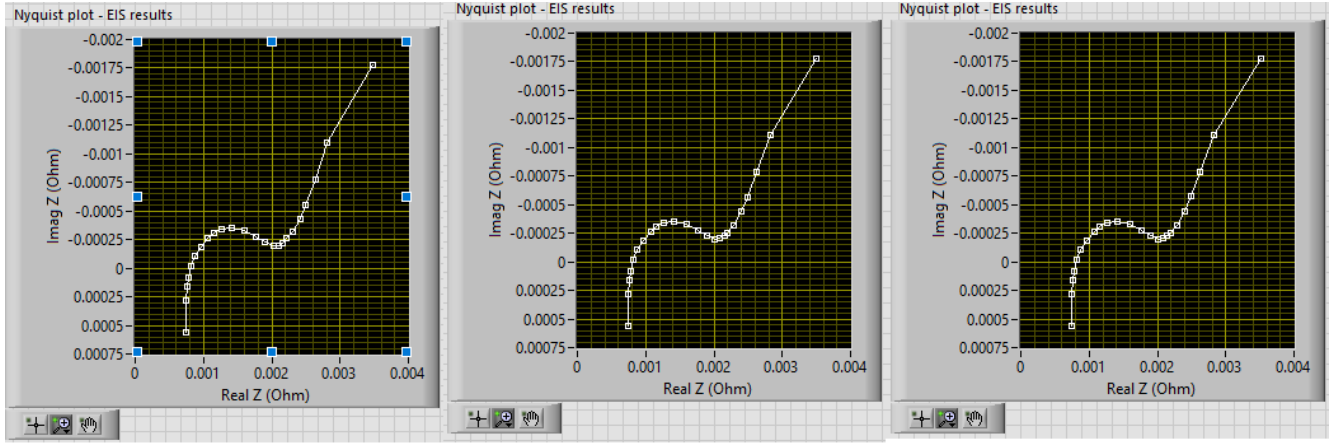
Summary of EIS based methods applied in literature

Method	Cell type	Potential of DUT	Frequency range	Duration	Accuracy
Single sinusoidal	All	0 – 11 V	10 mHz to 1 MHz	500 s	0,5 %
Multi sinusoidal	All	0 – 11 V	10 mHz to 1 MHz	unk	1 %
Dual PRBS	18650	2.0 – 4.25 V	0.1 Hz to 72 kHz	10.16 s	1 %
Ternary	unk	3.3 V	0.21 Hz to 3.5 kHz	4.7 s	3 %
DIBS	21700	3.6 V	3.1 Hz to 3 kHz	unk	unk
Multi-sine FFT	R6(AA)	3.7 V	0.1 Hz to 1 kHz	unk	2 %

Activities in 3-WP03 Batteries: Solutions for Testing and Modeling

3-WP03-002: Device and setup for quick diagnostic of automotive batteries

- Usage of HW setup (FTS developer) within p. TE01020020, improvement of SW.
- The setup consists of current source controlled by voltage generated through analog output of a multifunctional DAQ card NI6341. Generated harmonic current is superimposed to the DC voltage of the cell and AC voltage response is measured by the DAQ card.
- SW has been innovated for automatic set of temperature and SoC of the cell under test, which is then subject of EIS measurements.



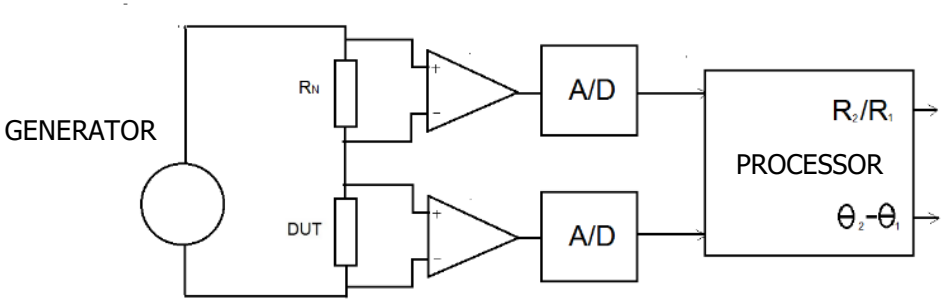
a) b) c)

Repeatability of the results for different AC current amplitudes a) 0.2 A, b) 0.5 A, c) 0.8 A. Measuring aged Winston LFP 90 Ah cell for frequency range from 5 mHz to 2 kHz.

Activities in 3-WP03 Batteries: Solutions for Testing and Modeling

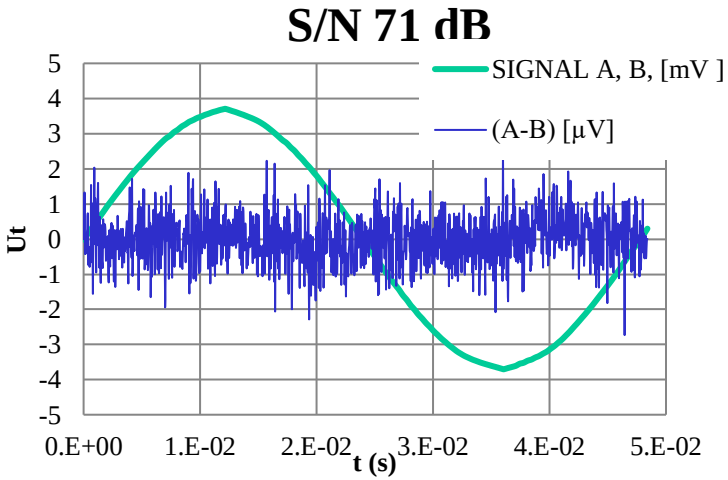
3-WP03-002: Device and setup for quick diagnostic of automotive batteries

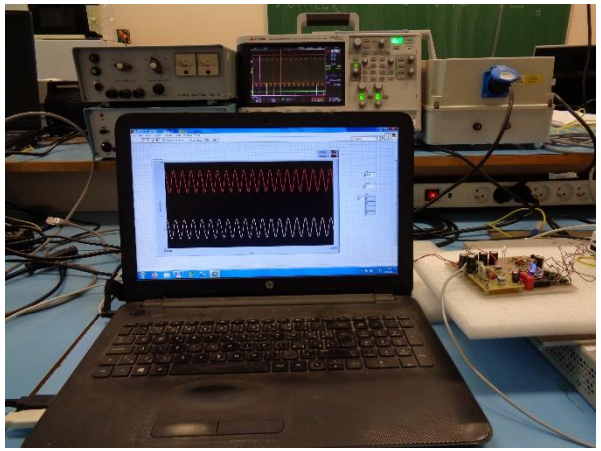
- Development process of HW setup at FEE.



Version 1

Signal-to-noise ratio 71 dB at 20 Hz
→ very low noise of measurement



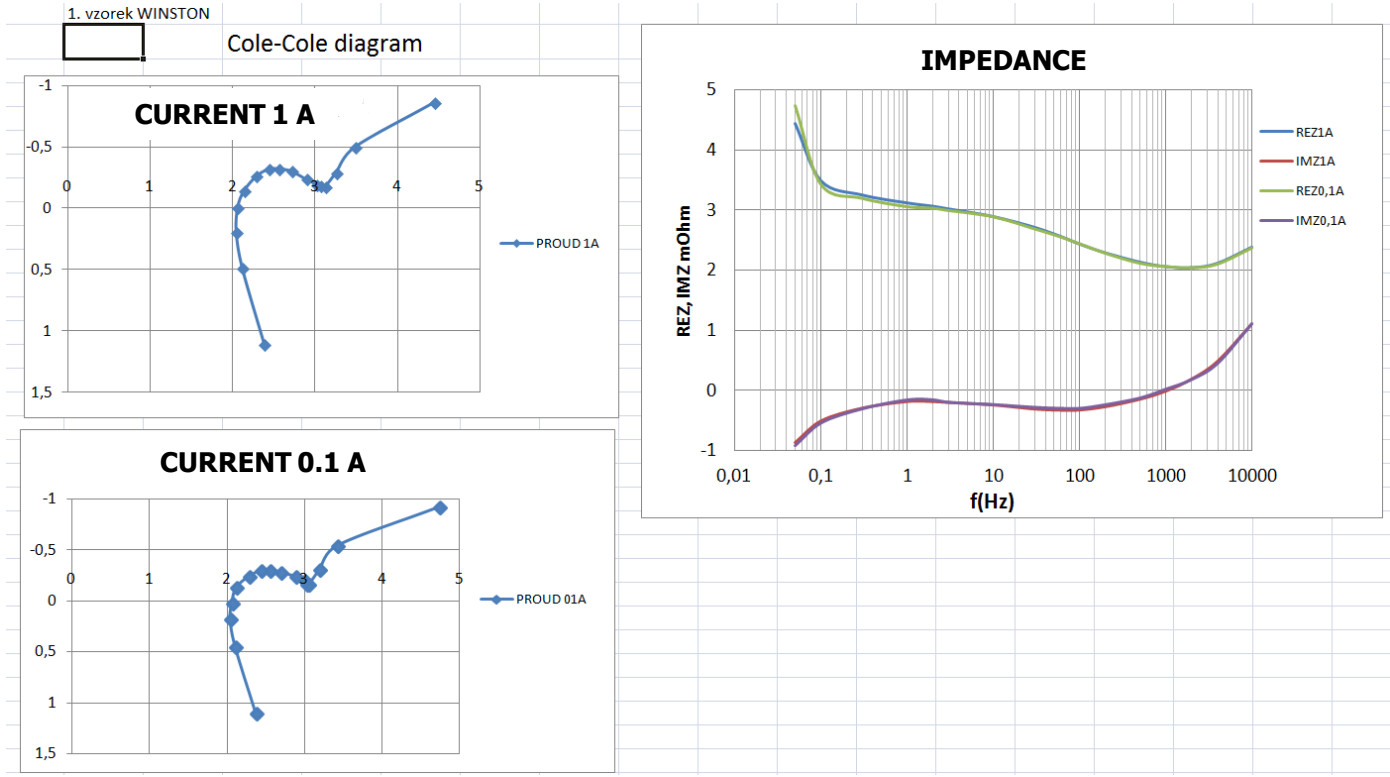


Version 2

Activities in 3-WP03 Batteries: Solutions for Testing and Modeling

3-WP03-002: Device and setup for quick diagnostic of automotive batteries

- Obtaining first good measurements:



Fulfillment of goals and deliverables of 3-WP03 Batteries: Solutions for Testing and Modeling

Current State of Deliverables and Fulfillment of Goals

- 3-WP03-001 | Complex traction battery model, R, XII./2025, CTU 0.9; GM 0.1 – **in progress & no major delays:**
  - Defined model's architecture. Defined test procedure and test samples.
  - Initiating laboratory tests.
- 3-WP03-002 | Device and setup for quick diagnostic of automotive batteries, G-funk, XII./2025, CTU 0.9; GM 0.1 – **in progress & no major delays**:
  - Review of electrochemical impedance spectroscopy methods
  - Development of HW setup for measurements
- 3-WP03-003 | Report on Milestones - Battery electric vehicle optimizer using complex traction battery model – results description, O, XII./2025, CTU 0.9; GM 0.1; **in progress & no major delays**:
  - Outcomes scheduled in the future.
- 3-WP03-004 | Report on Milestones - Quick diagnostic for automotive batteries via impedance measurements – results description, O, XII./2025, CTU 0.9; GM 0.1; **in progress & no major delays**:
  - Poster presentation about electrochemical impedance spectroscopy methods for lithium-ion battery diagnostics at ABAF 2023, and a conference proceedings article submitted to Monatshefte für Chemie - Chemical Monthly.

Fulfillment of goals and deliverables of 3-WP03 Batteries: Solutions for Testing and Modeling

List of Due Deliverables and Their Added Value

- **3-WP03-001** – aims for a modeling platform of an automotive battery module/pack, which can be used for vehicle optimization, test bench of state estimation algorithms, and an effective range prediction. It is expected to decrease the cost of the development process and to further add value to the end product.
- **3-WP03-002** – quick diagnostic method for lithium-ion battery cells, which will assess their current electrochemical state. It is expected to be used for battery evaluation, quality control, and cell sorting. It is expected to open the path for battery module diagnostics and to on-board diagnostics.
- **3-WP03-003** – reporting and dissemination of 3-WP03-001.
- **3-WP03-004** – reporting and dissemination of 3-WP03-002.

Current contribution of 3-WP03 Batteries: Solutions for Testing and Modeling

Assessment of the Contribution of Deliverables

- Complex traction battery model, its integration or used in optimization – 4-WP06, 3-WP04, 4-WP07, 3-WP12, 3-WP13, 4-WP09, 4-WP04 and potential NCK2 (BOVENAC) project.
- Diagnostics of automotive batteries and its application within the related activities – 3-WP11, 4-WP04 and potential NCK2 (BOVENAC) project.

Assessment of the Formal/Administrative Goals of the Work Package

- Currently the finances (reporting/spending), commercialization, and deliverables activities are carried and fulfilled primary by CTU.

Current contribution of 3-WP03 Batteries: Solutions for Testing and Modeling

Acknowledgment

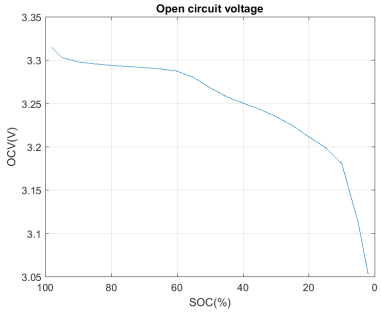
This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Centres II, project # TN02000054 Božek Vehicle Engineering National Center of Competence (BOVENAC).

Výtah z prací 2023-2025 na 3-WP03 Batteries: Solutions for Testing and Modeling

Václav Knap, vaclav.knap@cvut.cz

Výstup 3-WP03-001: Complex traction battery model má vyústit v komplexní model trakční baterie, který bude vhodný pro integraci s modely dalšími částmi vozu. Bude ho možné tak využít při optimalizaci designu nebo použití vozidla. Databáze modelů bude zahrnovat různé chemie lithium-iontových článků a závislosti jejich parametrů na různé vlivy, jako je například teplota, stav nabití, nebo stav stárnutí. Modely a vzniklá měření budou taky vhodná pro následné vyvinuti odhadovacích algoritmů stavů baterie a jejich validaci. Za dané období byly provedeny práce v rámci přípravy testování a testování, které dále povedou k parametrizaci modelů bateriových článků, jež jsou základním stavebním kamenem modelu bateriových modulů. Původce výstupů je ČVUT v Praze, zapojení ŠA a GM bylo formou konzultace na schůzkách.

Order	Test
1	Pre-conditioning test
2	Open-circuit voltage test
3	Pulse test
4	Capacity test
5	Dynamic discharge profile test
6	Driving profile test
7	Hysteresis test
8	Kinetic battery model characterization test
9	Entropy heat coefficient test
10	Heat generation test



Výtah z prací 2023-2025 na 3-WP03 Batteries: Solutions for Testing and Modeling

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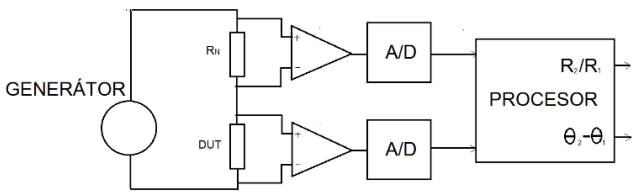
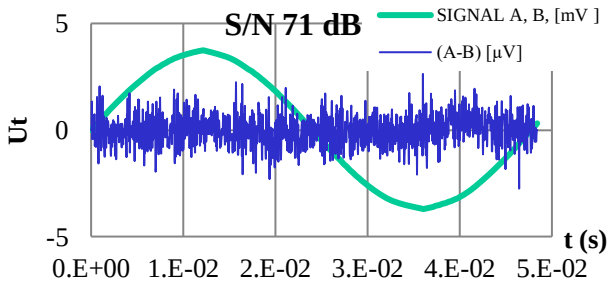
Diagnostika baterií je klíčová pro výběr a třízení bateriových článků při výrobě, pro monitorování provozních parametrů a prediktivní údržbu, a po skončení prvního života pro selekci a párování pro aplikace druhého života. Výstup 3-WP03-002: Device and setup for quick diagnostic of automotive batteries tak cílí na vyvinutí vhodné diagnostické metody, která bude rychlá, dostupná a přesná, a umožní vyšší kvalitu a bezpečnost při používání aplikací baterií. Za dané období byl proveden především vývoj HW laboratorního setupu pro měření elektrochemické impedanční spektroskopie, přičemž byl kladen důraz na významné potlačení šumu pro vyšší přesnost měření. Původce výstupů je ČVUT v Praze, zapojení ŠA a GM bylo formou konzultace na schůzkách.

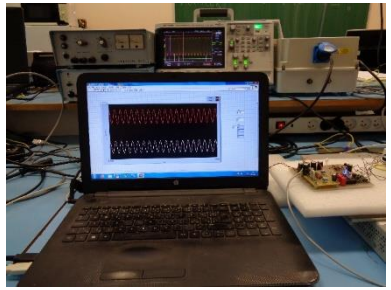
Schéma



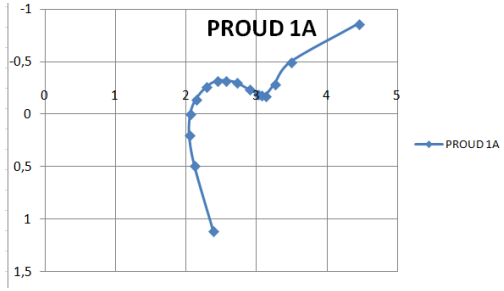
Šum



Náhled setupu



Naměřená křivka



Výtah z prací 2023-2025 na 3-WP03 Batteries: Solutions for Testing and Modeling

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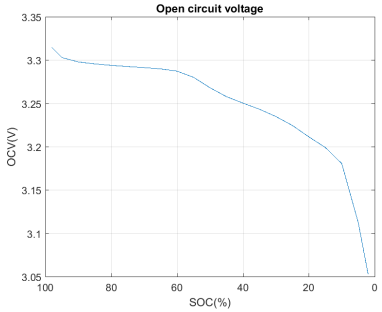
Outcome 3-WP03-001: Complex traction battery model will be suitable for integration with models of other parts of the vehicle. It will thus be used to optimize the design or use of the vehicle. The database of models will include different chemistries of lithium-ion cells and the dependencies of their parameters on different influences such as temperature, state of chargé, or aging state. The models and resulting measurements will also be useful for the subsequent development of battery state estimation algorithms and their validation. During this period, work has been carried out in preparation for testing and testing that will further lead to the parameterization of the battery cell models, which are the cornerstone of the battery module model. The originator of the outputs is CTU in Prague, the involvement of SA and GM was in the form of consultation meetings.

Order	Test
1	Pre-conditioning test
2	Open-circuit voltage test
3	Pulse test
4	Capacity test
5	Dynamic discharge profile test
6	Driving profile test
7	Hysteresis test
8	Kinetic battery model characterization test
9	Entropy heat coefficient test
10	Heat generation test



Výtah z prací 2023-2025 na 3-WP03 Batteries: Solutions for Testing and Modeling

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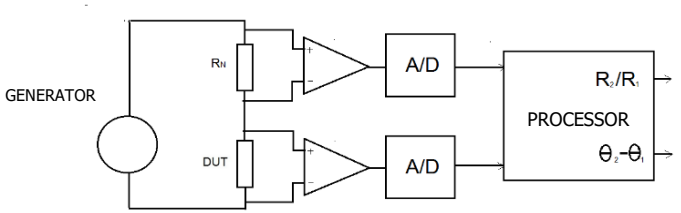
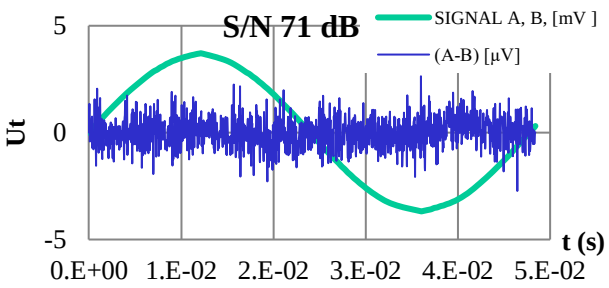
Battery diagnostics is critical for selecting and sorting battery cells during manufacturing, for monitoring operating parameters and predictive maintenance, and after the end of the first life for selection and matching for second-life applications. Output 3-WP03-002: Device and setup for quick diagnostics of automotive batteries thus aims at developing a suitable diagnostic method that is fast, affordable, and accurate, and enables higher quality and safety in battery applications. In particular, the development of a HW laboratory setup for electrochemical impedance spectroscopy measurements was carried out during the period, with emphasis on significant noise suppression for higher measurement accuracy. The originator of the outputs is CTU in Prague, the involvement of SA and GM was in the form of consultation meetings.

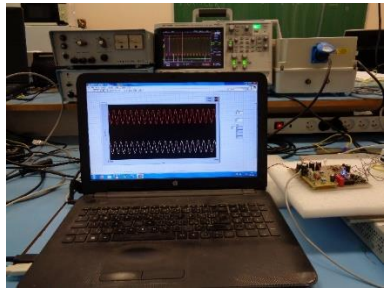
Scheme



Noise



Setup preview



Measured curve