ALBATROSS

Advanced Light-weight BATteRy systems Optimized for fast charging, Safety, and Second-life applications

Contents

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WP1 - Scoping, Engineering Design and Benchmarking

This newsletter aims to provide an in-depth look into the developments of the activities carried out for the different tasks of Work Package (WP) 1. We hope that you enjoy to read and know about them, as much as we have enjoyed working on them!

1. Scope and Requirements

The ALBATROSS project encompasses 7 different ambitious initial objectives, whose activities are led by different partners and that can be summarized as it follows:

Achieve a 20% weight reduction of the battery system.

- **Develop solutions and processes for sustainable dismantling/recycling of battery pack/modules** (materials, components and sub-systems) taking into account safety and automation.

- **Create flexible advanced battery management systems (BMS)** capable of being used on different types of packs and mid-sized vehicles with different use patterns, and underlying provision to be used in second life applications.

- **Develop advanced functionalities of BMS** to enable control of modules and packs and their remote maintenance and troubleshooting, software update and other functions, taking into account safety and modularity aspects at increased battery pack energy density, as well as health and environmental aspects over the lifecycle including cases of failure and reuse/recycling.

- **Develop systems compatible with high-power ultra-fast charging and related implications**, including high and low temperature charging, insulation, advanced models (including for instance data mining and big data on existing databases) for monitoring thermal state and estimation of application-dependant State of Health (SoH).

- **Develop and quantify performance-related test procedures for developed functionalities under real-world conditions**, including extreme conditions.

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- **Validate battery performance functionalities at full scale**, through pack integration into an existing vehicle to serve as a benchmark of the achieved performance.

- **Develop and quantify future safety-related test procedures** (e.g., venting/management of gases, battery failure warning signals, thermal propagation).

With these main goals and objectives, different activities and strategies have been adopted by the different partners that have been collaborating and offering their expertise along the years of development of ALBATROSS, creating important synergies not only for this project but also for the future of electric battery vehicles.

Following this clear definition of the path to be followed by ALBATROSS, different system specifications were well-defined as it will be seen in the next section.

2. System Specification

Following the scope and requirements previously detailed, the ALBATROSS partners worked together in close cooperation and shared valuable inputs to define the specifications to design, develop and manufacture the ALBATROSS system. Those initial technical specifications comprised five topics: General, Structural, Module, BMS (Battery Management System) and Heating/Cooling System.

The definition of previous specifications established the starting point for the developments to be made under the different topics. Some specifications can be found below and are still subjected to eventual modifications.

Overall, in terms of **general specifications**, the points established were mainly those related with the requirements established by the different preliminary objectives, which indirectly define the maximum weight and lifecycle of the ALBATROSS battery system.

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In what regards the **structural definitions**, those comprised the selection of different material combinations for the battery tray and the respective joining techniques.

In detail, weldable wrought aluminium 6xxx alloys and weldable cast Al-Si HPDC alloys were selected for the main structure, while CFRP were selected for the hybrid side beam. The weldable wrought aluminium 6xxx alloys were again selected for the manufacturing of the aluminium crash frames, given the versatility of this type of material. A thermoplastic-based CFRP or GFRP were the composites selected for producing the cover of the battery tray, so that to introduce an important weight reduction of this structure.

Regarding the **joining methods**, the different welding techniques selected were Friction Stir Welding (FSW), Cold Metal Transfer (CMT), Laser Spot Welding (LSW) and Laser Seam Welding (LSeW), and finally also Stitch Welding (SW).

For the **module specifications**, a pack energy density higher or equal to 200 Wh/kg before thermal management (TM) was established, whereas with TM, a pack energy density higher or equal to 180 Wh/kg was established.

Concerning the **battery cells**, the energy density was defined to be higher or equal to 250 Wh/kg and different types were initially considered such as cylindrical, pouch or prismatic.

For the **Battery Management System (BMS)**, the system architecture was defined as:

- Modular/flexible battery management system and slave units
- System-on-Chip design for high computing power
- Fast cell voltage and current acquisition at 1 kHz

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The software specification of the BMS included advanced algorithms such as:

- AI-based advanced SOx algorithms and thermal prediction
- Cloud-based predictive AI algorithms
- Anode control charging method for fast charging
- Electrochemical impedance spectroscopy (EIS) modelling
- Remote maintenance, troubleshooting and software update/calibrating
- Software from the partner ALGOLiON to provide State of Safety (SoC) and produce degradation/failure alerts
- A C-rate between 3C and 4C for fast charging (depending on cell selection)

For the **heating/cooling system**, the following specifications were defined:

- Cooling Type: Liquid-based (1 or 2-phase)
- Coolant: Water-based or Dielectric-based
- Heating Rate:
  - Catalytic heater: Thermal output power between 6 and 10 kW. The peak power and turn down ratio are still to be defined.
  - Interface: The heater ECU gets a control signal for the requested power from the BMS. For resistive heaters in the sensing system, 5 to 20 W elements are to be operated selectively to heat areas of 25 to 100 cm^2 on the cell surface.

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3. Benchmarked Parameters

A vehicle-based battery pack benchmark testing of the ALBATROSS baseline vehicle, a 2021 BMW i3 (125kW) was conducted by the partners University of Nottingham with sub-contract support from MAHLE Powertrain Limited. To evaluate the powertrain performance at several operating conditions, the vehicle was instrumented with several probes as listed below:

Vehicle instrumentation:

- 69 cell temperature probes taken at the cell positive terminal plates
- 16 cooling rack temperature probes
- 4 refrigerant temperature probes and 4 refrigerant pressure probes at the inlet and outlet of both the evaporator and compressor
- 1 refrigerant flow meter
- 5 cabin and ambient temperatures probes
- 15 CAN channels for data acquisition
- 4 HV current and voltage probes (Pack, Compressor, Heater, AC charger)
- 1 current and voltage (12V) probe

Temperature sensors were instrumented to monitor the cells temperature, cooling manifolds/rack and cooling inlet and outlet temperature. Refrigerant pressure and flow were also measured to allow the estimation of the heat dissipation from the pack.

Both temperature and pressure define the thermodynamic state of the refrigerant, hence the enthalpy level. Therefore, the heat was estimated as the product of refrigerant flow rate and the enthalpy difference between the inlet and outlet of the evaporator.

The battery pack behaviour was observed under both charging and rolling road driving conditions. A fast-charging condition at 150 kW was attempted at an ambient temperature of 18°C as representative of the state of the art, with the actual charge power level directly monitored.

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Specifically, the following charging tests were performed:

Shakedown testing:
- 150kW charge testing from a 30 to 60% State of Charge SOC
- 150kW charge testing from a 0 to 100% SOC

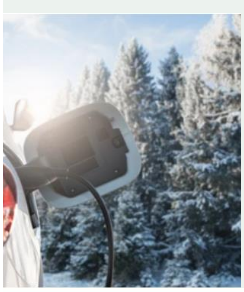
Although a 175kW capable charger was used, the data obtained confirmed that both charge and regeneration rate remained limited to a maximum of approximately 50 kW under all conditions tested (charging and regenerative braking on the rolling road) governed by the vehicle control software.

Active battery pack cooling was only observed in the 0-100% SOC test when an elevated terminal temperature of 38°C was recorded. Under the conditions tested, a moderate ambient temperature of only 18°C was verified.

It was generally concluded that the pack contains relatively high thermal mass, which enables reasonable passive temperature control without the need for any coolant to flow through the pack under the limited charging conditions tested.

“The OEM seems to have prioritised battery pack longevity over the need for ultra-fast charging capability.” – University of Nottingham

The driving condition was evaluated in a climatically controlled vehicle rolling road assembly at MAHLE, involving consecutive WLTC cycle tests conducted according to EU directive 2007/46/EC.



Due to the observations made during the upfront charging tests, a decision was made to elevate the chamber ambient temperature to 32°C in order to promote battery cooling. The tests were also repeated under cold test conditions at 0°C.

These harsher ambient conditions were assumed to assess the cooling and heating capability of the pack.

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The specific WLTC Tests included:

- Consecutive WLTC tests from an initial full charged state at 32°C (soaked) to a testing "break-off" (battery fully depleted) criterion at approximately 30% SOC.
- 0°C WLTC to break-off criterion (several driving cycles from 100% to 20% SOC with steps of approximately 10%)

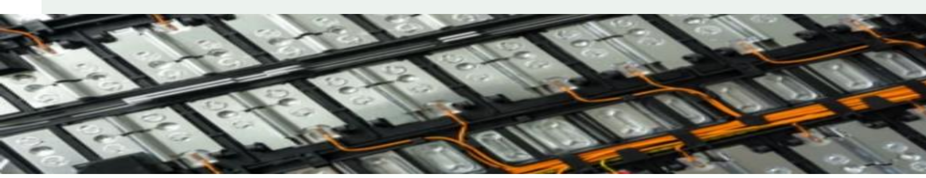
As observed in the charging test, the pack cooling trigger temperature appears to be 35°C (at the cooling rail) or 32°C (at the module).

Over the elevated temperature drive cycles, an average of 2.3 kW of heat was rejected from the pack, whereas during the 0°C operating condition, no heat rejection was observed, and further tests were performed at even lower operating temperature, in an effort to observe some active pack heating. These tests were performed soaking the car at -15°C with full SOC.

After approximately 21 hours, when the entire pack temperature was stabilised at -13°C, the heating elements powered on for about 1 hour until the pack reached a temperature of near 0°C. Following that, no heating was observed until a temperature of -13°C was reached again.

Typical observations made during the high temperature drive cycle tests were:

- Refrigerant flow into the pack of ~1.2 kg/min
- Cooling rail temperature reduced from ~35°C to ~25°C during active cooling
- Cell terminal temperature rise contained to within ~1°C
- Compressor electrical power consumption during pack cooling of ~1kW
- Compressor work during pack cooling of ~0.75kW
- Battery heat to refrigerant during pack cooling of ~2.3kW
- Condenser power during pack cooling of ~3.0kW



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4. Optimized System Design and Powertrain Model

The partner of the University of Nottingham embraced the objective of creating the powertrain models that will be fed into later work packages, which will allow for the calculation of the battery pack SOH at 300 000 km. These powertrain models were used to predict the impact of cell and module weight on the average mileage of the electric vehicle.

To simulate the powertrain of the electric vehicle BMW i3, the industry standard software GT-SUITE was used. This software is a versatile multi-physics platform for constructing models of general systems based on many underlying fundamental libraries:

- Flow library (any fluid, gas, liquid or mixture)
- Thermal library (all types of heat transfer)
- Mechanical library (kinematics, multibody dynamics, frequency domain)
- Electric and Electromagnetic library (circuits, electromechanical devices)
- Chemistry library (chemical kinetics)
- Controls library (signal processing)
- Built-in 3D CFD and 3D FE (thermal and structural)

The GT-DRIVE was used to simulate the WLTC cycle by assuming the BMW i3 parameters such as weight, battery density and some of the electric and road losses.

BMW i3 GT-Drive Model → WLTC Drive Cycle

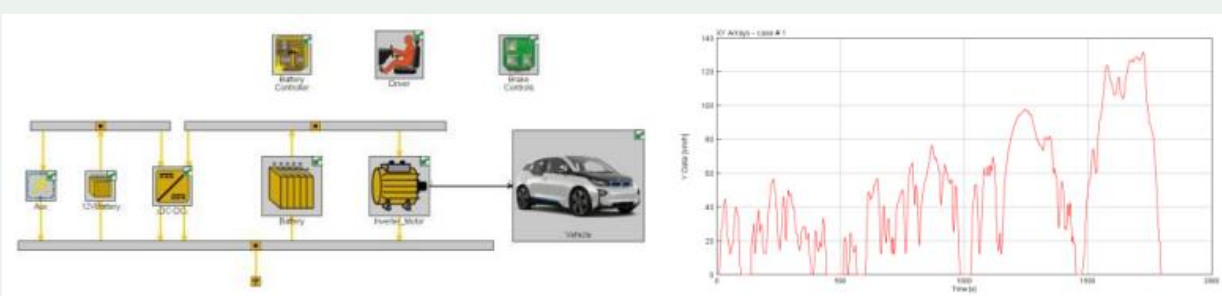

Figure 1. GT-Drive Model Layout

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The results from the activities of **Section 3. Benchmarked Parameters** were then compared to the powertrain modelling of the GT-DRIVE and the results achieved were comparable. In fact, the experimental data on the left indicates a 6.3% SOC loss whereas the GT-DRIVE simulation shown a 8.1% SOC loss.

The previous data will be employed to produce an accurate powertrain modelling to allow the validated model to predict extreme working conditions, which are very expensive and time consuming to test in real world conditions.

The impact of the battery mass on the range of the BMW i3 was also predicted using the GT-DRIVE and the results have shown that by going to higher battery capacity such as 72 kWh:

- The vehicle range increases to 486 km
- The weight increase of 200 kg does not impact the overall vehicle range

The powertrain modelling data will support other work packages where the weight impact will be studied.

Following this work, Yeşilova led the activities on the integration of the developments made systematically in other work packages to create a final design.

The partner University of Nottingham has bought a BMW i3 and disassembled the battery carrier to provide rough dimensions and pictures of the existing battery carrier to the partner Yeşilova.

The existing battery carrier was scanned and a .STL file was generated for overlapping the ALBATROSS design and verify whether the previously measured dimensions from the existing battery tray were accurate.

Following this, Yeşilova has started to study conceptual designs and design strategies for the profile extrusion.

YEŞİLOVA HOLDING, cleantron, Mercedes-Benz, CRF, ALGOLION, European Thermodynamics Limited, TWI, zemission, FEV, EWF, IREC, PST SENSORS, TECHNOVATIVE SOLUTIONS, NTNU Norwegian University of Science and Technology, cpi, Fraunhofer IWS, aimen, LEITAT, Ford, University of Nottingham, cidetec energy storage

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All the mounting and earth connections were validated and re-drawn to make sure consistency with the existing parts and the .CAD file generated from those points. The alignment of the mounting points was also checked both physically and digitally to ensure a correct assembly.

The GT-SUITE model was updated with the latest weight calculation using the .CAD file provided by the partners Yeşilova and Cleantron.

The components calculated were:

- Cylindrical cells
- Tubing
- Dielectric fluid
- Electrical components
- Busbars
- Fittings and sensors

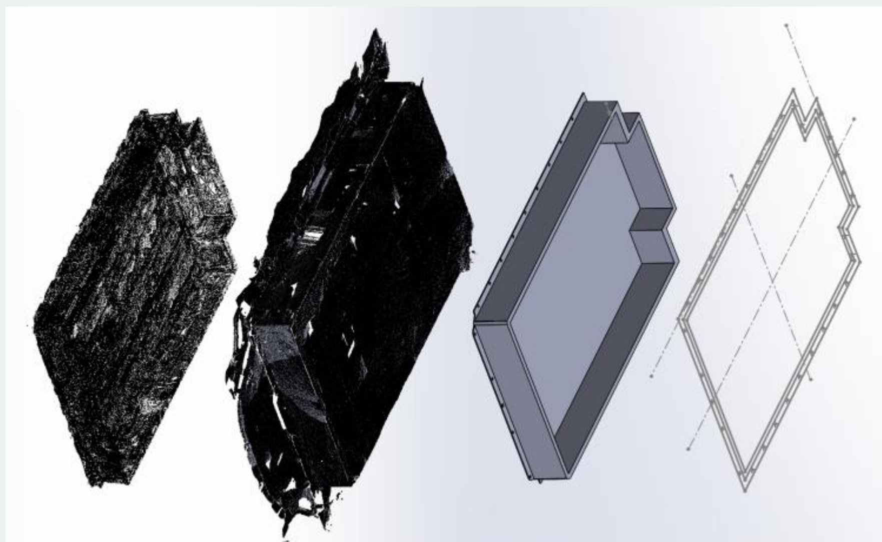

Figure 2. Battery tray and cavity validation

The cooling system was also implemented on the GT-SUITE model to account for the weight of the system and state of the charge of the battery. The simulation results are very similar to the previous study, as the impact of the weight is very minimal to the range of the vehicle.

A validation of the battery pack is still to be carried out at a later stage and since the model created within the software is parametric, more realistic values can be easily introduced and new results can be generated.

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