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MSc – Motorsport Engineering

Hybrid Powertrain and Control ACEA7007

Drive-cycle Requirement Specifications

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Abstract

This project focuses on assessing and evaluating a proposed drive cycle for an electrically powered sidecar aiming to break the current land speed record in the Group B1 (Motorcycle with a Sidecar) Division B, Type VII (Solar/Electric Power). The aim is to identify potential issues early in the development process, optimise the powertrain system for performance and efficiency, and recommend powertrain simulation methods that can be used for the virtual development and testing of the sidecar. The project utilises Simscape and Simulink blocks to model physical aspects of the problem, including a point mass vehicle model and torque demand on ideal motors transmitted via chain drives to tires. Additionally, electric motor modelling is used to analyse, optimise, control, and simulate electric motors and their applications. The project highlights the importance of simulation software in the automotive industry for testing, validating, and optimising vehicle designs and offers recommendations for improvement in motor power, battery modelling, and weight transfer simulation for the provided drive cycle.

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1. Introduction

Powertrain modelling and simulation are essential parts of vehicle development. It allows engineers to simulate the performance of the powertrain system in a virtual environment before construction. This helps to identify potential issues early in the development process, saving time and money. Simulation also allows engineers to optimise the powertrain system for performance, fuel efficiency, and emissions. In addition, powertrain modelling can help to identify the optimal powertrain architecture for a given vehicle and to test the embedded software.

A customer has requested a reassessment and evaluation of a proposed drive cycle of an electrically powered sidecar intending to break the current land speed record. The client has asked for an analysis, explanation and recommendation of powertrain simulation methods that can be used for virtual development and testing of the sidecar.

Simscape is a computational tool designed for physical modelling within the Simulink environment, which enables the rapid development of models for various physical systems. This tool facilitates the construction of physical component models that integrate seamlessly with block diagrams and other modelling paradigms based on physical connections. Custom component models can be created using the Simscape language, a MATLAB-based tool that allows for text-based authoring of physical modelling components, domains, and libraries (MathWorks, 2023). The Simscape tool is especially useful for developing control systems and testing system-level performance and can model a wide range of systems, including electric motors, bridge rectifiers, hydraulic actuators, and more. Simscape also employs specialised simulation technology to achieve real-time simulation, which can be adjusted to limit the computation effort per time step as necessary to achieve real-time performance. The tool is well-suited for applications such as hardware-in-the-loop (HIL) testing, training simulators, and other scenarios requiring synchronised execution with a real-time system.

1.1. Aim and Objective

- Assess and evaluate a proposed drive cycle intending to break the current land speed record.
- Analysis of simulation methods to be used for virtual development and testing.

1.2. Methodology

The methodology for this assignment is as follows:

1. Investigate the provided drive cycle.
2. Fix and identify shortcomings.
3. Evaluate modelling methodologies appropriateness for a sidecar.
4. Where applicable, apply modelling techniques.
5. Synthesise plan for vehicle modelling and analysis.

2. Supplied Drive Cycle

This project aims to break the current FIM world land speed record in the Group B1 (Motorcycle with a Sidecar) Division B, Type VII (Solar/Electric Power), which currently stands at 110.389 mph over a mile (FIM, 2022). Positives aspects of the provided drive cycle are: the representation of physical conditions at Bonneville (Parkin, 2018) with the specific air density and rolling resistance accounted for in first principle equations, the fontal area was estimated, and the drag coefficient appropriately adjusted incorporating a rider (Caines, 2018), the battery selection and limitation of use in the top 70% SOC (Metaye, 2022). Aspects of the drive cycle that can be improved are motor power adjusted to account for efficiency losses properly, more through battery modelling accounting for packaging, thermal characteristics and battery cooling, and more accurate simulation for weight transfer. Figure 2-1 shows the initial drive cycle, capable of attaining 302 km/h, and Figure 2-2 shows the cycle corrected for motor and chain drive efficiencies (Scott, 2023) as well as battery cooling losses (Charlton, 2022), capable of attaining 10km/h less.

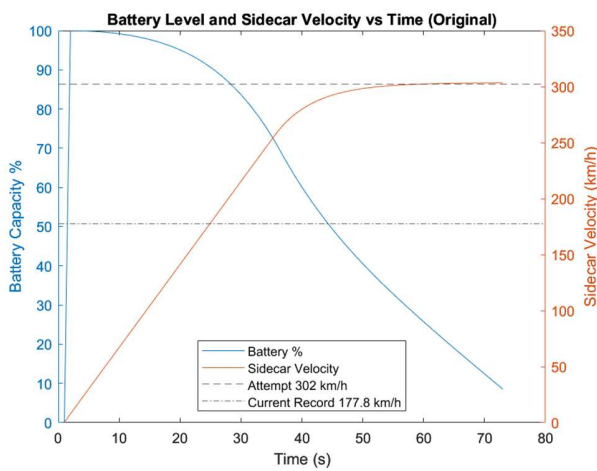


Figure 2-1: Original Drive Cycle

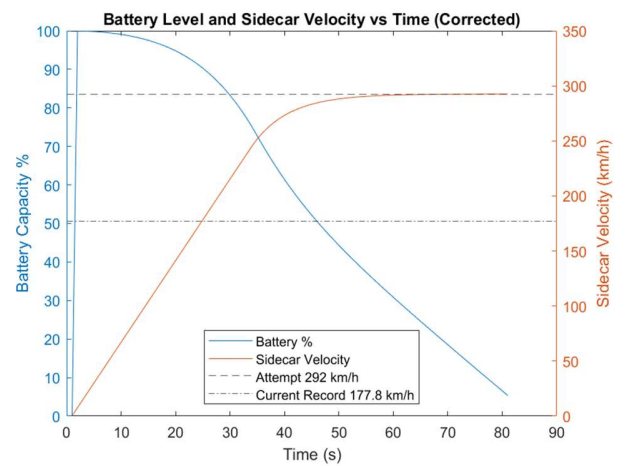


Figure 2-2: Corrected Drive Cycle

3. Mechanical Modelling

The automotive industry relies heavily on simulation software to test, validate, and optimise vehicle designs. One such software, VI-CarRealTime, is a real-time vehicle simulation tool that allows for real-time analysis of a vehicle's behaviour. This software is based on the ADAMS simulation platform and is widely used to simulate and analyse various aspects of vehicle behaviour (VI-GRADE, 2023). Another popular simulation tool is Simulink, a block diagram environment for multidomain simulation and model-based design. Simulink is widely used for simulating dynamic systems (MathWorks Student Competitions Team, 2023). Additionally, MathWorks offers Simscape Multibody, a modelling and simulation tool that allows for the simulation and visualisation of complex systems, providing a 3D animation of the system response (MathWorks, 2023). These simulation tools are critical for the automotive industry, enabling researchers and engineers to analyse and optimise vehicle performance, safety, and design.

As the customer is focused on powertrain design and optimisation, the approach for modelling the physical aspects of this problem utilises a point mass vehicle model using Simscape and Simulink blocks. The drive cycle from Figure 2-2 is added to the reference speed diagram. The PID compares the reference speed to the current vehicle speed and inputs a torque demand on the ideal motors. Torque is transmitted via chain drives to tyres which apply forces to the chassis (represented by a mass). Aerodynamic drag and rolling resistance friction forces are applied via a Simulink model and transitional friction Simscape block, respectively. These blocks make use of first principal equations and accurately express the MATLAB code resistive forces.

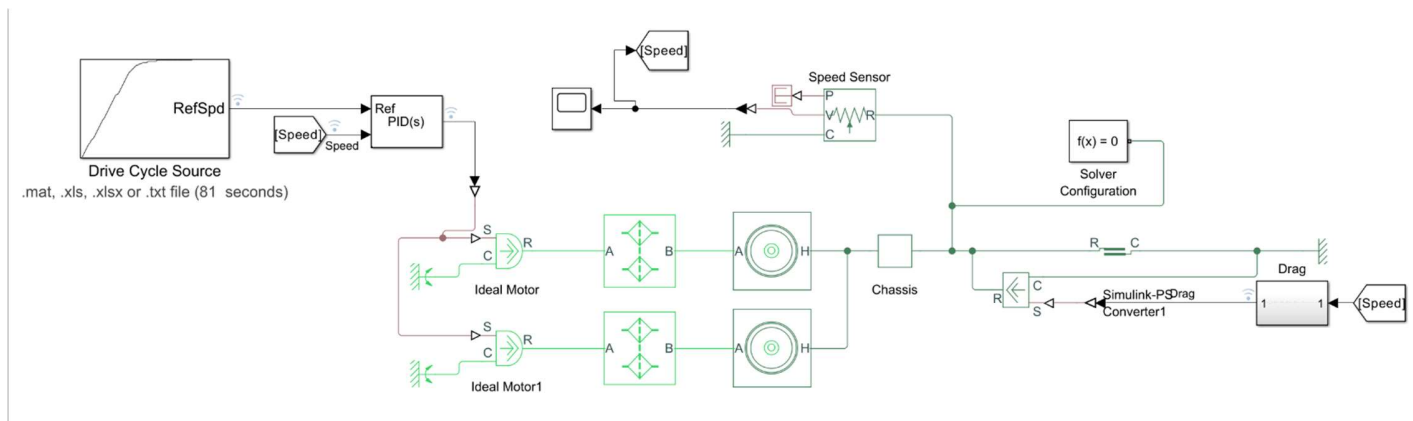


Figure 3-1: Mechanical components of the system modelled.

4. Electro-physical Modelling

Electric motor modelling is creating mathematical representations of electric motors and their dynamics. This technique can be used to design, analyse, optimise, control, and simulate electric motors and their applications. The fidelity and complexity of electric motor modelling can be adjusted depending on the task objectives and requirements. Simulink is a toolbox that can be used for electric motor modelling within MATLAB, providing a graphical environment for block diagram modelling and simulation (MathWorks, 2023). Simscape Electrical is another toolbox that can be used for modelling electrical power systems (MathWorks, 2023). It provides specialised blocks and components for modelling electrical circuits, machines, drives, converters, and batteries. These toolboxes enable detailed analysis and design of electric motors and their applications, including the simulation of behaviour and performance under different operating conditions and scenarios. Other toolboxes and products are available for electric motor modelling within MATLAB, such as Powertrain Blockset, Motor Control Blockset, and System Composer. These toolboxes and products offer additional features and capabilities for modelling electric motors and their applications in various domains and contexts.

The Motor & Drive (System Level) block (Figure 4-1) is recommended for this application. It is a tool for modelling a generic motor and drive with closed-loop torque control, allowing it to function with the PID controller, simulating a driver/torque demand (T_r). The block abstracts the motor, drive electronics, and control to facilitate rapid system-level simulations. The block limits the simulation to the range of torques and speeds defined by a torque-speed envelope. Numerous ways to parametrise electrical torque and losses utilise supplied tabulated information (MathWorks, 2023). To describe this model, parameterisation by "Tabulate torque envelope with speed and supply voltage" is suggested for Electrical torque and "Tabulated efficiency data as a function of speed and torque" for Electrical losses.

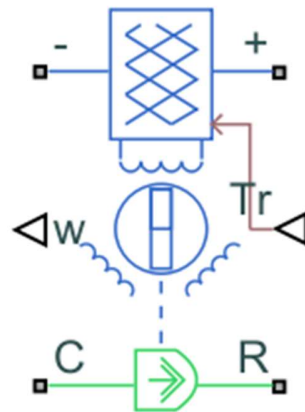


Figure 4-1: Motor & Drive (System Level) block

5. Electrical/ Battery Modelling

5.1. The DC Voltage Source and Battery (System Level)

The DC Voltage Source and Battery (System Level) blocks can be used to verify that the system is functioning as expected. The Battery (System-Level) block can simulate hybrid and battery electric drives at a medium-level fidelity for drive cycle analysis. The block is a simplified version of the Battery (Simscape Electrical) block, which uses the same parameters where applicable. The Battery (System-Level) block does not support battery fade, ageing, dynamics, or temperature-dependent properties (MathWorks, 2023).

5.2. Simscape Battery

5.2.1. Theory

Simscape Battery provides parameterised models and design tools for building battery systems. With the help of these tools, users may create digital twins, model battery pack topologies, create battery management systems, and examine the behaviour of battery systems in normal and fault situations. The interactive design tool battery pack model builder creates simulation models automatically based on the specified pack architecture and has cooling plate connections for analysing electrical and thermal reactions. Models of battery packs and management systems with parameters show how to do tasks like cell balancing and state-of-charge estimates. These models can be used to determine cell requirements, perform trade-off analyses and hardware-in-the-loop (HIL) testing, and generate readable and efficient C/C++ code. Figure 5-1 shows the growth of a pack from a single cell. Geometry (length, height thickness, tab location, width and height) is necessary to model cells Pouch Cells. From this, cells are packed to form parallel assemblies, then modules, module assemblies and finally, packs (MathWorks, 2023).

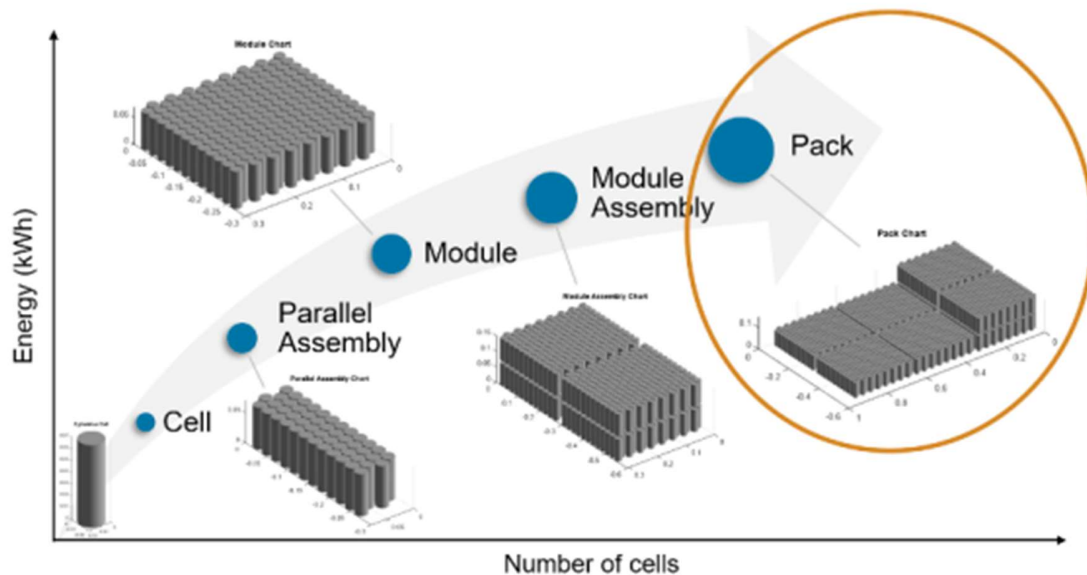


Figure 5-1: Growth of a pack from a single cell (MathWorks, 2023)

Figures 5-2 to 5-4 showcase different simulation strategies. Pack simulation can be simplified by lumping cells together depending on the necessary complexity and available computing power. Figure 5-2 shows a pack of cells modelled as singular cells. Figure 5-3 shows the same pack modelled as a lumped module. Figure 5-4 shows custom grouping (MathWorks, 2023).

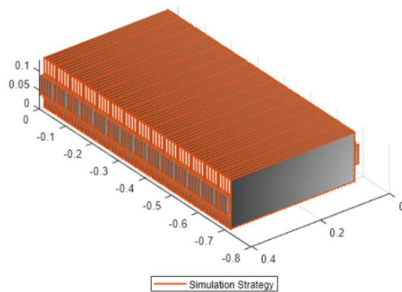


Figure 5-2: Singular Cells Pack

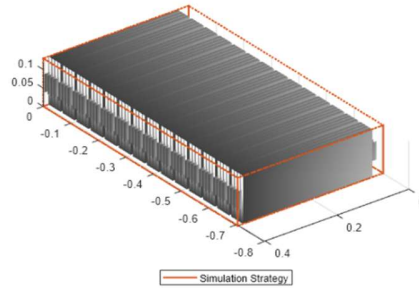


Figure 5-4: Lumped Cells Pack

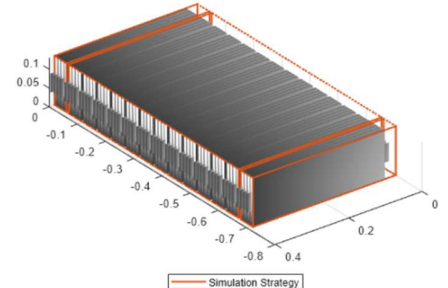


Figure 5-3: Custom Modelled Cells Pack

5.2.2. Application – Battery Pack

The battery selected by the client is a GREPOW 40C High Discharge Battery model number (GRP6374135). Table 5-1 describes the battery parameters and Figure 5-5 a picture of four cells (GREPOW, 2023).

Table 5-1: Selected Cell information (GREPOW, 2023)

Model No.	C Rate	Capacity (mAh)	Voltage (V)	Weight (g)	Thickness (mm)	Width (mm)	Length (mm)
GRP6374135	40C	5000	4.2	116.0±3.0	5.9±0.2	73.0±1.0	134.0±1.0

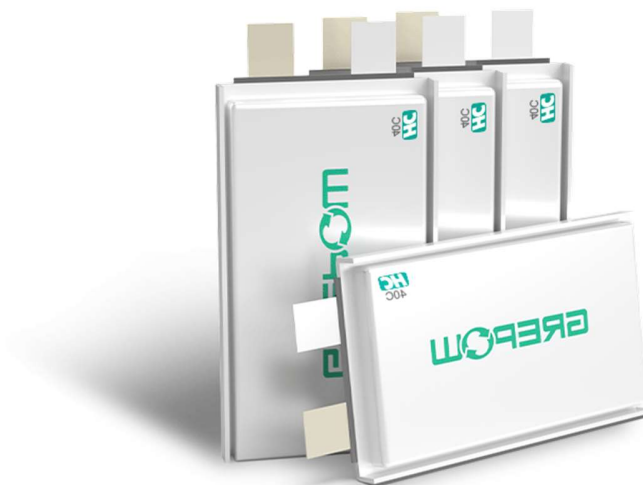


Figure 5-5: GREPOW Cells (GREPOW, 2023)

A basic pack was constructed using the given information, and the result is shown in Figure 5-6. The code `BatteryPack` (referenced in the Appendix) describes the creation of a battery pack model using the Simscape toolbox. The battery pack is constructed by combining multiple modules, which are made up of parallel assemblies of battery cells. Each parallel assembly consists of four battery cells in parallel, and the modules themselves are made up of six parallel assemblies in series. The battery pack is created by assembling multiple modules together, with a 4mm gap between each parallel assembly and a 0.02m gap between each module assembly. The battery pack is then visualised using the `BatteryChart` function, and the number of models used to create the pack is displayed. Overall, the code provides a simple but effective way to create a battery pack model using Simscape that can be used for further analysis and simulation.

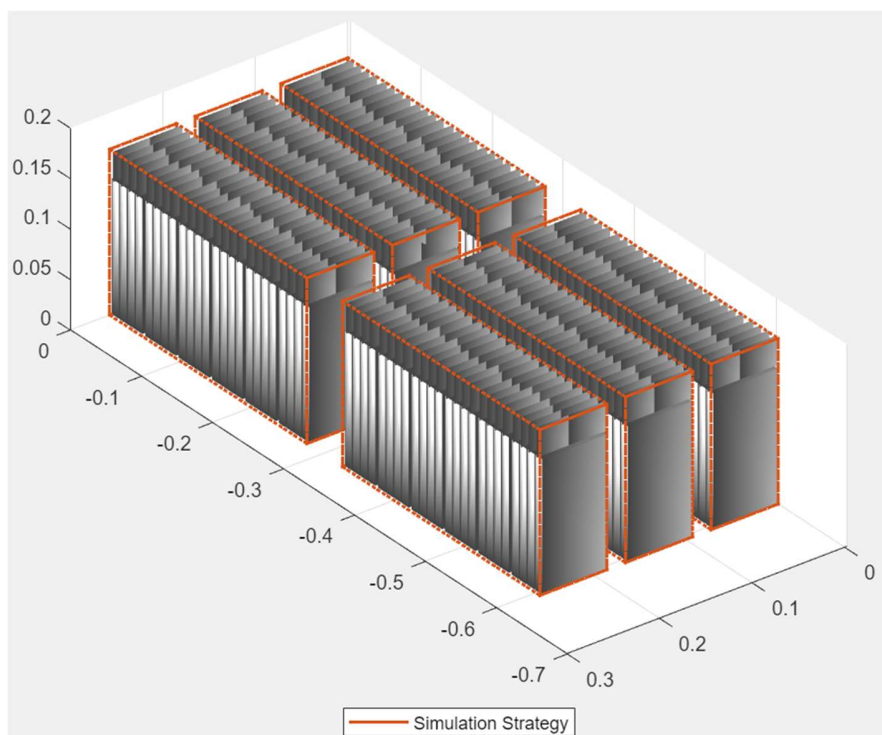
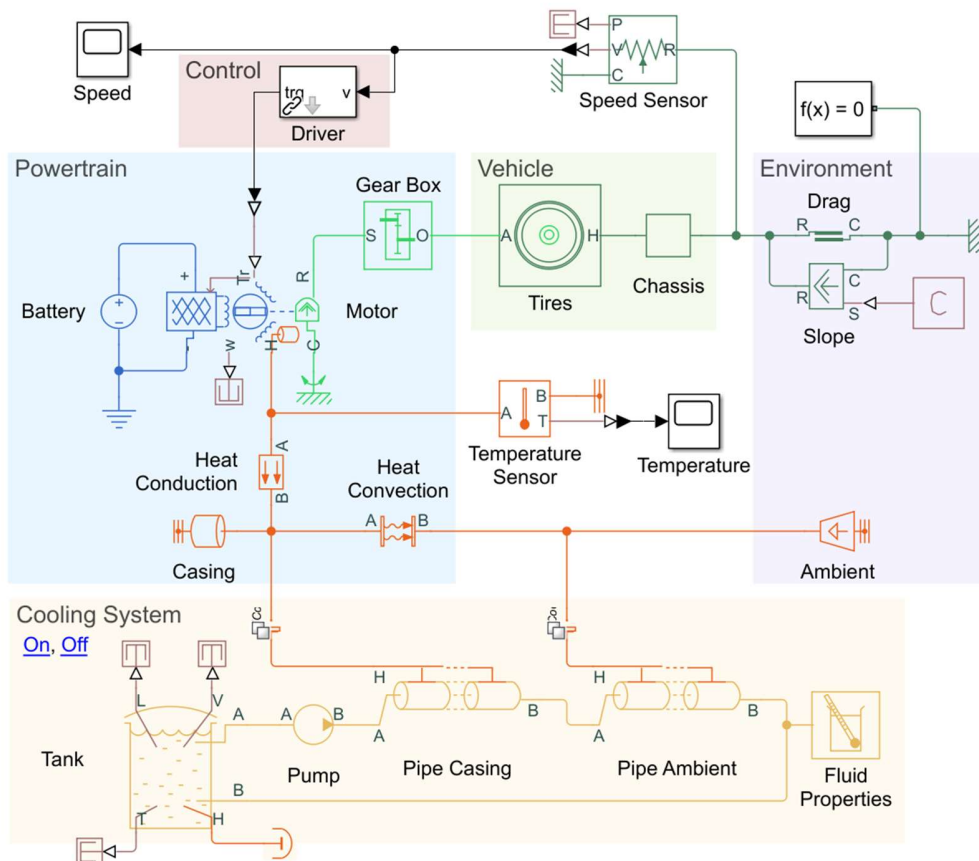


Figure 5-6: Sidecar Battery Pack

6. Thermal Modelling

MATLAB and Simulink offer thermal modelling capabilities through thermal libraries, which contain blocks specific to the thermal domain allowing for the modelling of fundamental thermal effects, such as insulation and heat exchange. These effects can be interconnected to model multidomain physical systems (MathWorks, 2023).

Various examples of thermal modelling and management using MATLAB and Simulink are available, including modelling a permanent magnet synchronous motor with thermal dependency, quantifying insulated-gate bipolar transistor thermal losses, simulating a simple induction hob system, using a Peltier device as a thermoelectric cooler, controlling a fan with a thermistor, and optimising an inverter liquid cooling system (MathWorks, 2023). To apply thermal modelling to the current sidecar problem, thermal ports will be turned on on the battery and motors, and a radiator system similar to (Miller, 2023) is necessary for heat rejection. Figure 6-1 shows the thermal port of the motor turned on. Heat is transferred via the orange connections to the yellow radiator pipes for cooling and recirculation.



Battery Electric Vehicle With Motor Cooling

1. Cooling System: [On, Off](#)
2. [Plot torque and temperature](#) of motor ([see code](#))
3. [Explore simulation results](#) using [sscexplore](#)
4. [Learn more](#) about this example

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Figure 6-1: BEV Model with Cooling (Miller, 2023)

7. Conclusion and Recommendations

Table 7-1 lists the project's different parts to be modelled, the proposed tool and the information necessary for simulation. The driver will be modelled as a PID controlled with the inputs of an ideal drive cycle as a reference and current speed. The vehicle body will be a mass with external forces acting on it to cause motion. The driving chain sprocket radii and tyre rolling radii need to be input, as well as rolling resistance frictional and aerodynamic drag factors. To model the EMRAX 268 motor, a tabulate torque envelope describing motor speed and the supply voltage is necessary for electrical torque, and a tabulated efficiency as a function of speed and motor torque is needed for electrical losses. If the customer decides to use a liquid-cooled motor, then motor thermal characteristics are required. Individual cell geometry, masses, packing limitations and cooling needs are required to develop a Simscape Battery model of the pack and to develop the necessary cooling.

As the simulation relies on various assumptions, conducting physical tests on the motor and battery with the controller will allow for more accurate modelling. The fidelity of the modelling is directly proportional to the client's development requirements. If future work requires suspension/vehicle dynamic modelling, Simscape Multibody is suggested as the simulation method.

Once the model is built, a recommendation to the client is to investigate different gear ratios/ sprocket radii, radiator configuration, cooling fluids and optimising pack geometry for cooling and weight saving. New motor configurations can be investigated; the FIM rules allow for 3-wheel drive; (EMRAX, 2023) state: "Two same-sized EMRAX motors can be stacked together (stacked electric motor), therefore power / torque is doubled". A further recommendation for the client is to investigate new motors as the current EMRAX 268 Air Cooled, Medium Voltage motor produces 9% more power than the current motor suggested (EMRAX, 2023). These changes would require additional battery capacity changing the vehicle weight.

Table 7-1: Simulation Break Down

Project Part	Proposed Tool	Required Information for Simulation
Driver	PID Controller	Ideal drive cycle, current speed
Vehicle Body	Mass Block with Applied Forces	Mass with external forces. Driving chain sprocket radii, tyre rolling radii, rolling resistance frictional and aerodynamic drag factors
EMRAX 268 Motor	Motor & Drive (System Level)	Motor speed and supply voltage for electrical torque, efficiency as a function of speed and motor torque. If liquid-cooled motor, motor thermal characteristics required
Battery Pack	Simscape Battery Model	Individual cell geometry, masses, packing limitations, and cooling needs

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9. Appendix – File List

This is a list of the files submitted along with this report:

- Power Source Selection: Initial hand calculation estimates for the battery. (Excel)
- Original_sidecar: Original drive cycle script supplied by the client. (MATLAB)
- Corrected_sidecar: Corrected drive cycle script. (MATLAB)
- LandSpeedDriveCycle: Corrected drive cycle results. (Excel)
- ModelWithIdealMotor: Model to simulate physical forces (Simulink)*
- ModelWithIdealBattery: Ideal motor model replaced by a Motor & Drive and a constant DC Voltage source (Simulink)*
- BatteryPack: Geometric model of the battery pack (MATLAB)/ (Simscape Battery)

* On some occasions, the LandSpeedDriveCycle has to be reimported into the Simulink models.