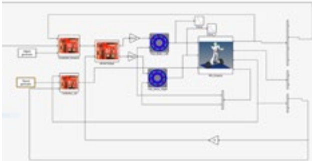
TECHNICAL DOCUMENT

MULTIDISCIPLINARY DEVELOPMENT OF AN UPRIGHT SCOOTER

A mechatronics system consists of mechanical, electrical and control subsystems. Typically, each subsystem is developed and optimized independently. The example of an upright scooter illustrates the benefits of developing a mechatronics product with system integration present from early stages of development. Early on awareness of the behavior of other subsystems together with deep integration later, during the design exploration and optimization stage, highlight the importance of easy subsystem fidelity selection.

Background Information

Developing all subsystems of a product inhouse can yield more accurate simulation results which leads to improved performance and lower costs with better adherence to requirements. To attain the benefits of full system development, a collaboration between groups where each subsystem is designed is necessary. Furthermore, the simulation of a system of systems with the possibility of choosing the model fidelity of each subsystem brings better results at each development stage. This fidelity tuning not only helps to direct the focus on a subsystem while maintaining an overview of the whole product but also allows for design exploration and optimization methods.



System of systems model

Activate® & MotionSolve™ co-simulation provides motor requirements

An upright scooter is an ideal mechatronic example to illustrate the benefits of a holistic system development approach since it combines mechanical structures, motion dynamics, e-motor drives and corresponding controls. By utilizing the unique licensing system and the native integration between Altair products for Model-Based Development, Multibody Dynamics and Low Frequency Electromagnetics, a system of systems model can be created and simulated for the upright scooter to optimize motor sizing, controller design, and overall vehicle performance.

The Challenge

The development of an electric upright scooter has a set of narrow requirements with the main objective being the stability and responsiveness of the driving performance as well as the energy efficiency of the system.

Maximized energy efficiency, which leads to a longer range, is linked to the motor design, the weight of the whole system, the controller scheme and the road profile. In parallel to this objective, there are constraints regarding the size of the motors which are connected to the two wheels of the scooter but also the performance in certain driving conditions.

The strategies to improve energy efficiency while also adhering to the constraints are interconnected and demand the study of different principles. Motor sizing is achieved by finding the torque requirements when simulating the controller as it interacts with the multibody model. Later, the motion dynamics of the scooter are not only affected by the weight of the system, but also the performance of the motors and the controllers.

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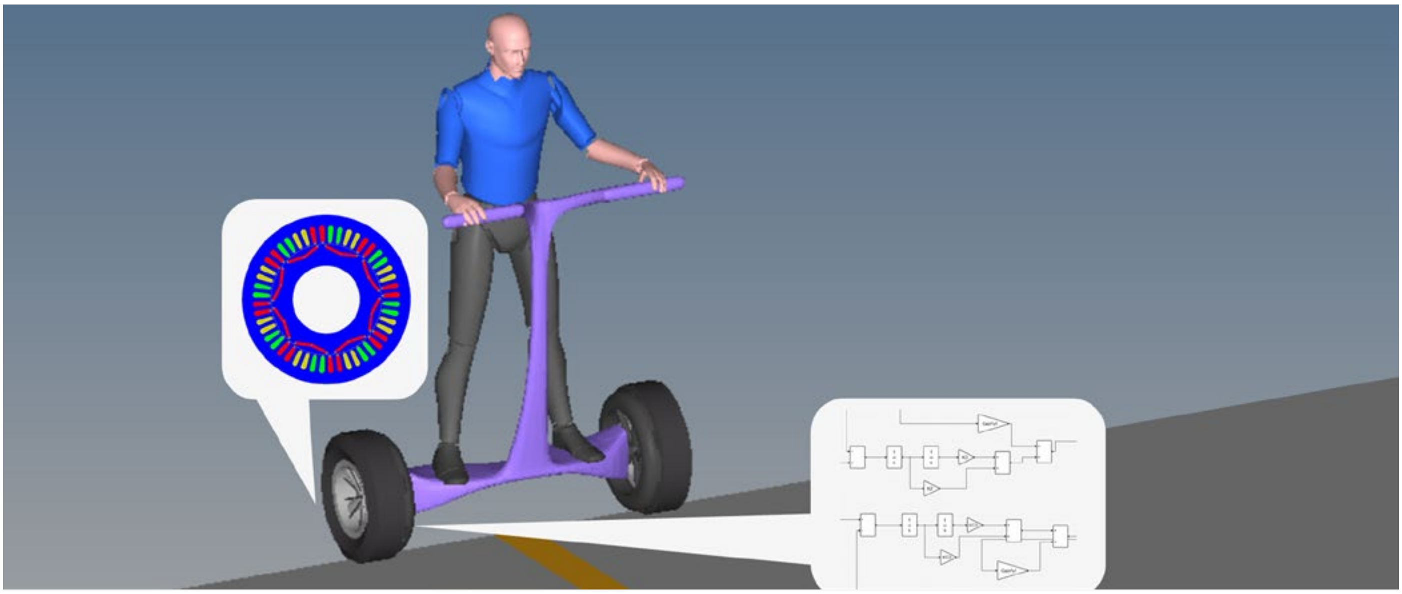


The discrepancy between the torque command coming from the controllers and the torque output of the motors, the controller scheme and the driving profile can all increase the vibrations and the instability of the system. To further refine the design, a complex Electromagnetic CAD model is preferably used instead of a simplified equation-based motor model.

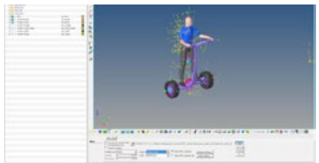
The driving performance goals consist of the scooter maintaining stability when in operation but also when it is stopped. Complementing the energy efficiency strategies, a high-fidelity controller and motion dynamics model is needed to optimize the overall vehicle performance.

With a typical siloed development approach, each subsystem is simulated independently. And when it is necessary to combine them, there is often a sacrifice in the fidelity of some subsystems. This can give decent, rapid, primary results. To further improve the final product however, a more integrated approach is necessary. There is a clear need for a fidelity choice depending on the development stage.

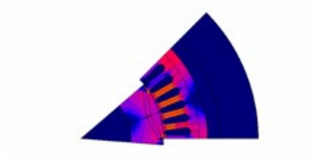
Breaking down the silos – The upright scooter system can be split into 3 different subsystems: the controller, the motors, the mechanical structure. Each one is designed at different development stages – first to set the control scheme, then the torque requirements for the motor (dimensioning) and later to investigate and improve the performance of the overall system.

Collaboration between departments, when designing a multi-disciplinary system, should preferably take place from the first stages of development. The data acquired from the development and simulation of one subsystem can assist on the more accurate design of the rest as they are interconnected. To assist this, a clear workflow is needed, where the interconnections and the data exchanged between subsystems are taken into account. Furthermore, staying within the same ecosystem with deep integration between different tools can motivate collaboration more.

Building the controller and setting the requirements – The breaking down of silos is emphasized from the early stages of development of the upright scooter and specifically during the design of the controllers. The controllers are required to calculate the appropriate signal to the motors to provide balance to the scooter and govern its movement. With Altair MotionSolve®, a multibody model can be built to represent the motion dynamics of the mechanical vehicle system. This can be then analyzed on two different planes: on the longitudinal plane to study the balance and on the transverse plane to adjust the torque of each wheel based on the vehicle's roll angle. Through these analyses the multibody model can be linearized, and the state space matrices of the system are exported. The state space matrices can serve as a reduced order model (ROM) of the dynamical system. Beyond that, they are also used to design the optimal controller in Altair Activate®, practically building the controller with the data taken from the multibody model.



Linearizing and exporting ROM in MotionSolve™



Investigating motor performance in Flux™

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Motor Sizing – The response of the scooter to the torques, calculated in MotionSolve, is part of the feedback loop to the system. At this stage the torque command output of the controller directly functions as the torque input to the multibody model. Through this multidisciplinary process a torque profile is created which can help in the design of the motor.

During the motor sizing stage, the requirements of the motors are derived from the previous simulations. The objective is to find the torque demands of the system but also the dimension limitations of the motors since they are attached to each wheel. The coupled control and dynamical system calculate the torque needed to achieve the desired scooter performance. With the torque and dimension requirements Altair Flux® can be used to identify the best motor design.

Selecting Motor Design – A static ROM based on magneto-static look-up tables (LuTs) can be exported using the built-in capabilities of Flux. This model is then added to Activate to represent the motors. The ROM allows for rapid simulations and therefore it is perfectly suitable to compare the performance of the system with different motors. Four tests are applied to provide an initial evaluation under different road and driving profiles:

1. start & stop with maximum velocity on smooth road
2. lane change / turning on smooth road
3. uphill climb on smooth road
4. rough road

These scenarios provide wide-ranging insights to the torque commands of the controller and the response of the system with each motor design.

Developing in Collaboration – The workflow for the development of the upright scooter stresses the benefits of collaboration between groups at every stage:

1. Optimal controller design: state space matrices need to be exported from the multibody models
2. Motor sizing: Requirements can be set from a model which has the controllers and multibody system in co-simulation
3. Motor selection: Co-simulation of the controls, motion dynamics and static ROMs exported by the motor FEA CADs.

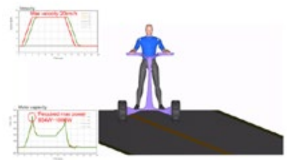
With the combination of Altair software and the built-in tools to co-simulate or export ROMs, the workflow can become clearer bringing more accurate results, quicker. Furthermore, the unified Altair ecosystem eases discussion between groups resulting in a seamless transition from one development stage to the next.

A System Integration Platform

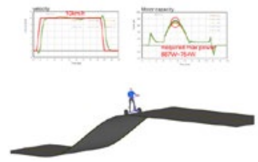
In the previous steps, fidelity switching was emphasized where, depending on the development stage, engineers can quickly switch between the high fidelity model or the ROM for each subsystem. During validation there is a need for a more detailed model. Activate functions as an integration platform where the 3 subsystems exchange data to better simulate the system of systems.

After the preferred motor is chosen, the system can be investigated more extensively for validation but also for more accurate results on the performance of the system. To incorporate the model for motion dynamics from MotionSolve and electromagnetics from Flux, Activate comes with built-in co-simulation blocks for both domains. In a purpose-driven manner, the fidelity of each subsystem can be selected depending on the type of validation. For a better overview of the system, a high-fidelity model was used for each subsystem providing the most accurate results, practically co-simulating the Electromagnetic FEA model (Flux) with the controller model (Activate) and the multibody dynamics model (MotionSolve).

The 4 tests can then be rerun. During our investigation, we found that the fluctuations in the torque coming from the motors, caused vibrations in the longitudinal direction and increased instability. Prior to the inclusion of the co-simulation of the Flux model, neither issues were expected leading to design adjustments after validation.

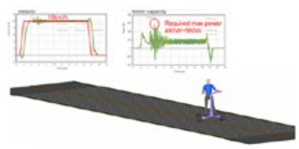


Start & stop with maximum velocity on smooth road



Uphill climb on smooth road

Lane change / turning on smooth road



Rough road

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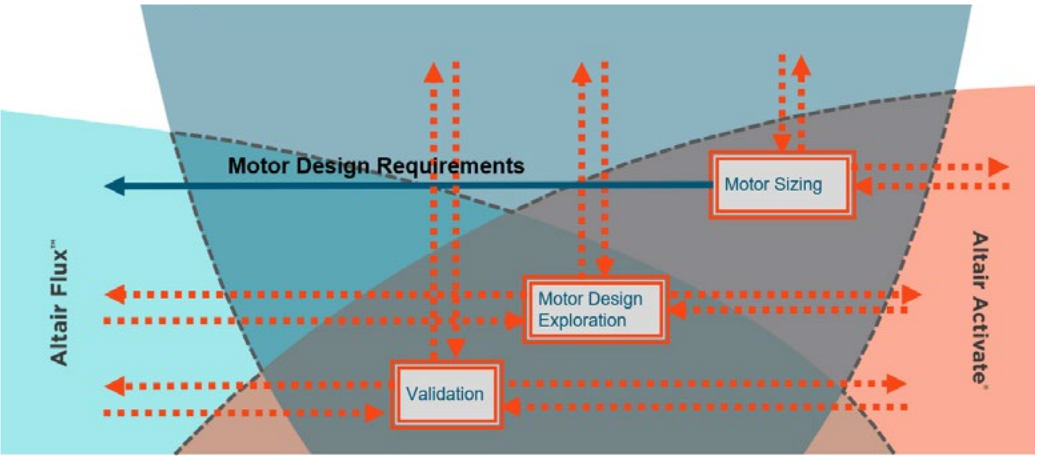

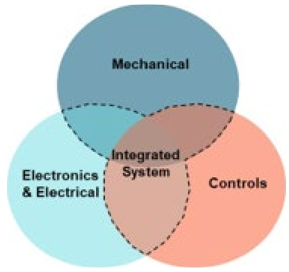

Integration of the mechanical, electrical (motors) and the controls subsystem

Using Activate as an integration platform, each development group can focus in the respective discipline and seamlessly co-simulate the three subsystems bringing high accuracy results. In this case, these high-fidelity models led to the redesign of the system as the torque ripples were not found until the validation stage.

Multidisciplinary Development with Affordability

The development of a mechatronics product demands for a variety of tools used by different engineering groups. This typically raises the software costs significantly. With the unique Altair Units licensing system, the cost is dictated by the number of concurrent usages of any Altair Units supported product at any given moment. In a mechatronics product development scenario this allows for the independent modeling and simulation of the Mechanical, Controller and Motor subsystem with just the cost of using MotionSolve.

	3D Multibody Model	Multibody ROM (ABCD Matrix)	Controller	3D Motor Model	Motor ROM
Multibody System Designer	✓	–	–	–	–
Controller Design	–	✓	✓	–	–
Motor Sizing	✓	–	✓	–	–
Design of Motors	–	–	–	✓	–
Motor Design Exploration	✓	–	✓	–	✓
System Validation	✓	–	✓	✓	–

Fidelity switching throughout the development process

Working with Altair

A holistic system development approach with connected subsystems can lead to a more optimized product while reducing the time-to-market. The choice between complex FEA simulation or ROM of each subsystem and the option for co-simulation allows for rapid simulations during design exploration and the in-depth analysis of the finalized design. The easy switch between high fidelity models and ROMs which bring quick results reduces development time and promotes a more streamlined, collaborative product development process.

Altair is a global technology company that provides software and cloud solutions in the areas of product development, high-performance computing (HPC) and data analytics. Altair enables organizations across broad industry segments to compete more effectively in a connected world while creating a more sustainable future.

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