Multidisciplinary Optimization of an Electric Motor for an Automobile and Extension to a Model-Based Systems Engineering Approach

Designing a modern electric motor for an electrified automobile requires striking the perfect balance between cost, weight, and performance. From a modeling and simulation standpoint, predicting the overall performance of the motor requires multiple multi-disciplinary analyses, including electromagnetic, thermal, and stress analyses.

The traditional Computer-Aided Engineering (CAE) process, which consists of setting up a model, running the simulation, post-processing data, reviewing results, extracting the outputs of one simulation that are inputs into another, and iterating until an acceptable design is achieved is simply not possible when the validation of the design requires this many models and types of solvers.

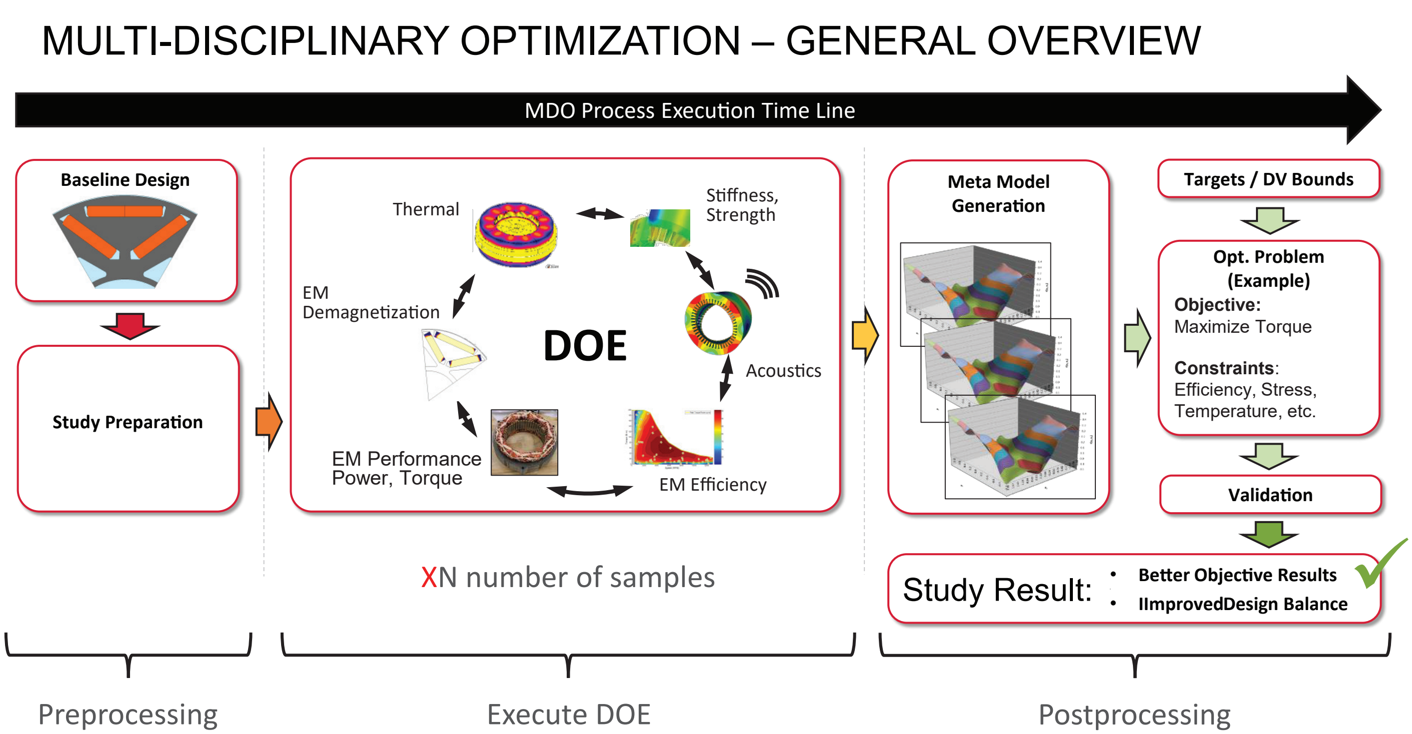


Figure 1. Diagram of the overall Design & Optimization Process

/ Brief Introduction

As a brief introduction, ModelCenter® is a framework for model based engineering and allows users to:

- Automate any modeling and simulation tool
- Integrate these tools together to create repeatable simulation workflows
- Set simulation parameters
- Automatically execute workflows
- Streamline the development of complex systems by connecting systems architecture and requirements to modeling and simulation tools

The general design and optimization process includes the following steps:

- Generate a baseline design using e-motor design tool
- Define the Design of Experiments (DoE) to explore the design space
- Run the DoE (including electromagnetics, thermal & mechanical analyses)
- From the results of the design space, create reduced order models that will replace the physics-based in the multi-disciplinary analyses so the workflow can be executed much faster, thus making optimization feasible
- Set-up the optimization problem
- Run the optimization problem to come up with the optimum design

ModelCenter®'s powerful integration capabilities provide engineers with the ability to quickly build automated multidisciplinary workflows. In this example ModelCenter was used to solve the multidisciplinary problem of the design of an electric motor for an automobile and brought together electromagnetic, thermal, and structural performance criteria in a single workflow so that all the performance aspects and constraints can be simultaneously considered to design an efficient motor. The individual disciplines are evaluated using Altair solvers – Flux Motor (initial baseline motor design), Flux (EMAG), and OptiStruct (thermal & stress analyses).

ModelCenter® provides an easy way to connect the different analysis tools into a sophisticated workflow. There is a graphical representation of the workflow which makes clear the order of execution of the components and the data dependencies between them. When components do not depend on each other, it is possible to run them in parallel to reduce execution time. An optimizer executes the workflow to search through the design space and find the best answer.

The design optimization problem is defined as follows:

MULTIPHYSIC OPTIMIZATION LOOP WITH MODELCENTER®

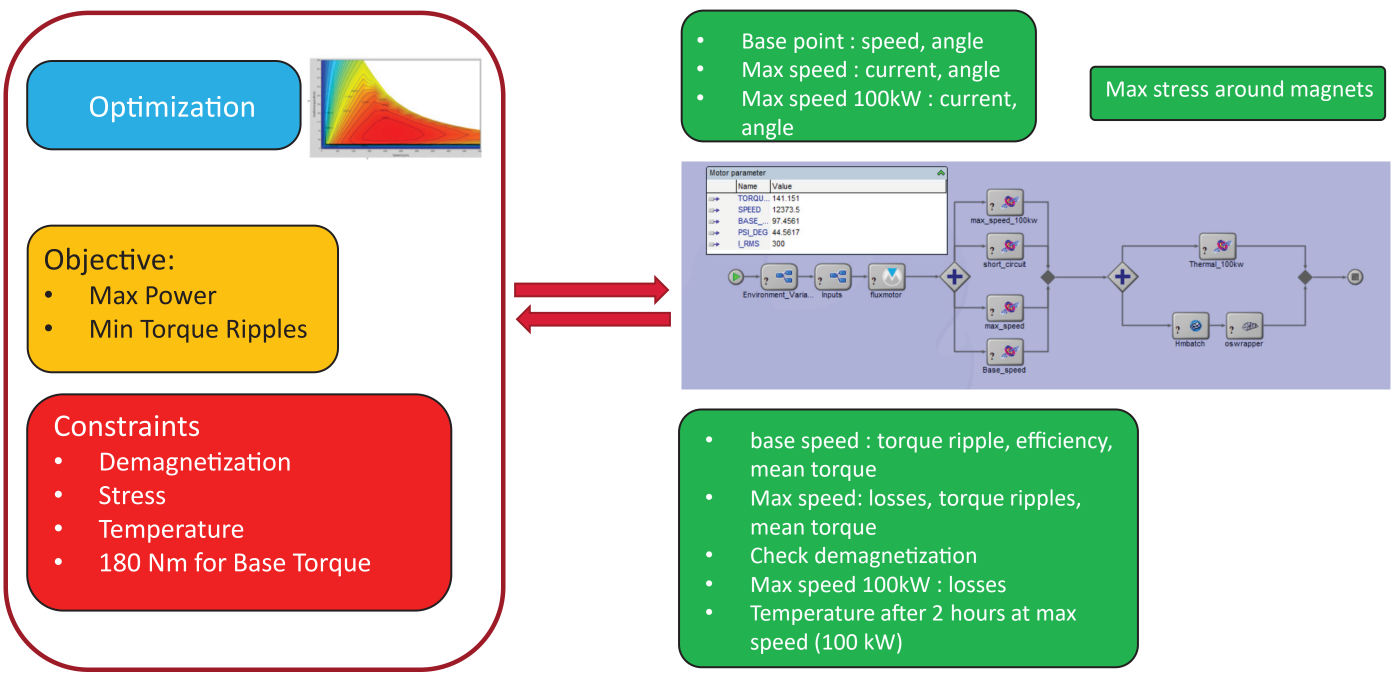
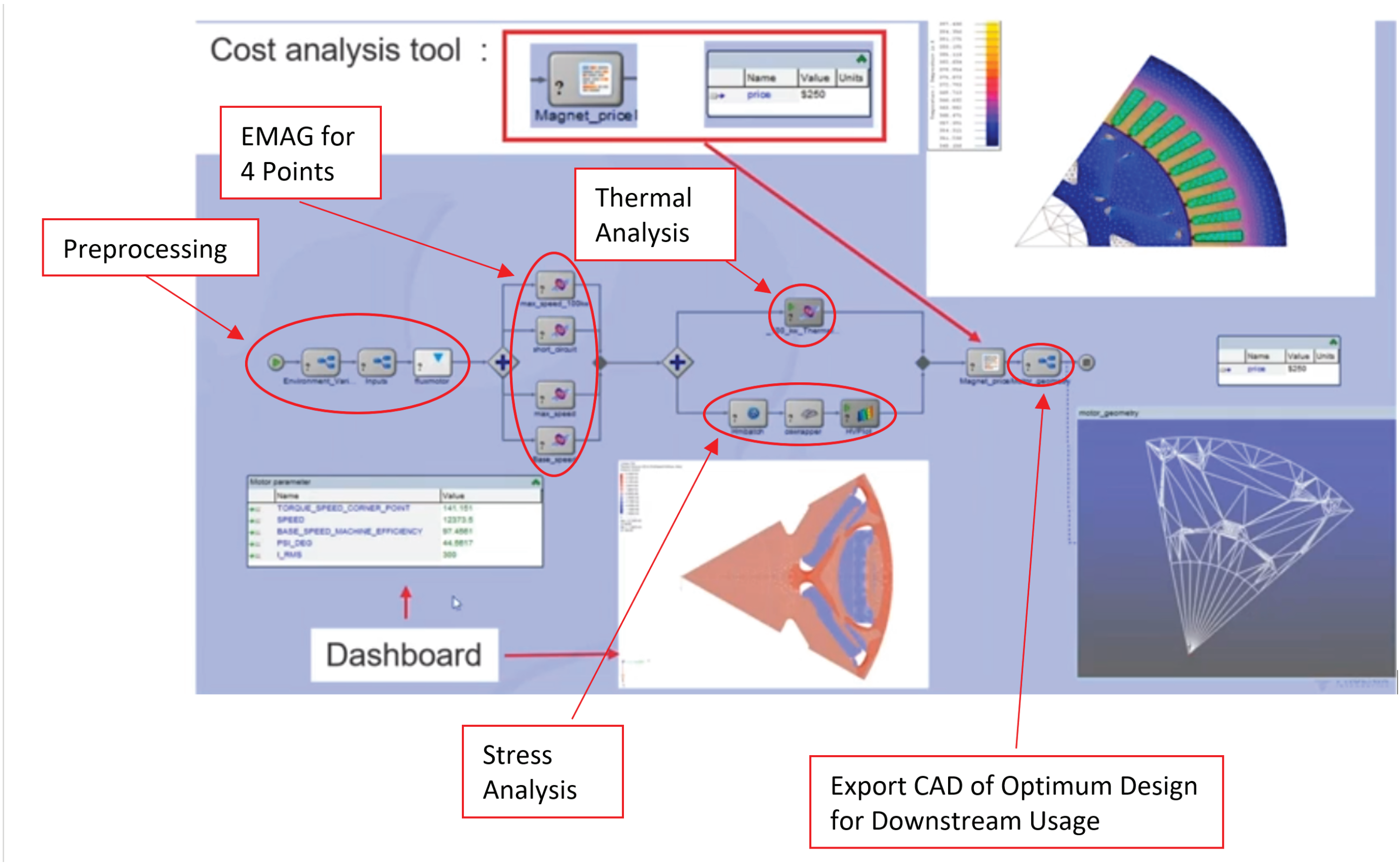


Figure 2. Multiphysic Optimization Loop with ModelCenter®

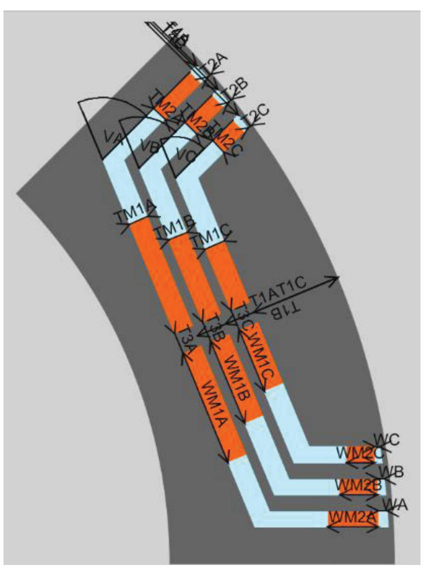
The figure below shows the screen capture of the associated ModelCenter workflow:



The ModelCenter® GUI allows the user to extract key information as the workflow is being executed, which provides a real time dashboard while the design iteration loops are running. In this particular instance, we selected a table with some of the key design variables and outputs, as well as graphic images of geometry along with stress & thermal results. This allows the analyst to get real time feedback on the analysis results and to monitor progress.

After the workflow has been created, we can explore the design space to gain insight into our design by generating and running a design of experiments.

/ Design of Experiments



	Active	Label	Varname	Lower Bound	Nominal	Upper Bound
1	☑	Magnet::TM1A (mm)	var_1	2.5000000 ...	3.0000000 ...	3.3000000 ...
2	☑	Magnet::TM2A (mm)	var_2	2.5000000 ...	3.0000000 ...	3.3000000 ...
3	☑	Magnet::T2A (mm)	var_3	1.3500000 ...	1.5000000 ...	1.6500000 ...
4	☑	Magnet::T3A (mm)	var_4	1.3500000 ...	1.5000000 ...	1.6500000 ...
5	☑	Magnet::T4A (mm)	var_5	2.7000000 ...	3.0000000 ...	3.3000000 ...
6	☑	Magnet::WM1A (mm)	var_6	8.0000000 ...	13.500000 ...	13.500000 ...
7	☑	Magnet::WM2A (mm)	var_7	6.0000000 ...	10.000000 ...	10.500000 ...
8	☑	Magnet::WA (mm)	var_8	0.4500000 ...	0.5000000 ...	0.5500000 ...
9	☑	Magnet::TM1B (mm)	var_9	2.5000000 ...	3.5000000 ...	3.8500000 ...
10	☑	Magnet::TM2B (mm)	var_10	2.5000000 ...	3.5000000 ...	3.8500000 ...
11	☑	Magnet::T2B (mm)	var_11	1.3500000 ...	1.5000000 ...	1.6500000 ...
12	☑	Magnet::T3B (mm)	var_12	1.3500000 ...	1.5000000 ...	1.6500000 ...
13	☑	Magnet::WM1B (mm)	var_13	6.0000000 ...	10.000000 ...	10.000000 ...
14	☑	Magnet::WM2B (mm)	var_14	4.0000000 ...	7.0000000 ...	7.0000000 ...
15	☑	Magnet::WB (mm)	var_15	0.4500000 ...	0.5000000 ...	0.5500000 ...
16	☑	Magnet::TM1C (mm)	var_16	2.5000000 ...	4.0000000 ...	4.4000000 ...
17	☑	Magnet::TM2C (mm)	var_17	2.5000000 ...	4.0000000 ...	4.4000000 ...
18	☑	Magnet::T2C (mm)	var_18	1.3500000 ...	1.5000000 ...	1.6500000 ...
19	☑	Magnet::T3C (mm)	var_19	1.3500000 ...	1.5000000 ...	1.6500000 ...
20	☑	Magnet::WM1C (mm)	var_20	5.0000000 ...	6.0000000 ...	6.0000000 ...
21	☑	Magnet::WM2C (mm)	var_21	2.0000000 ...	3.0000000 ...	3.3000000 ...
22	☑	Magnet::WC (mm)	var_22	0.4500000 ...	0.5000000 ...	0.5500000 ...

Figure 3. Twenty-Two Design Variables for the Magnets

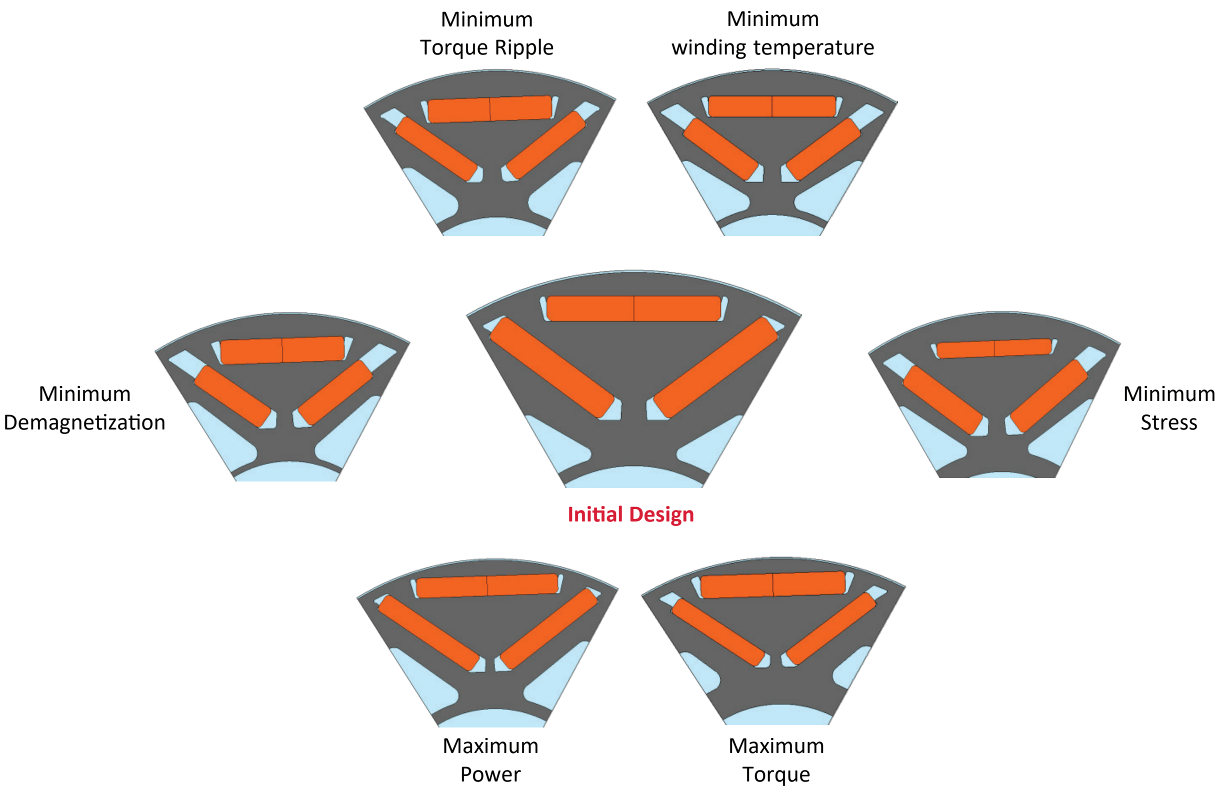


Figure 4. Design Exploration on DoE Results on Magnets

Based on the results of the DoE, we are now able to identify which design variables have the most impact on our design and performance targets, and what are the usable ranges for these variables. This will help us define the optimization problem properly so we can run an optimization loop to find best the compromise based on the current objectives.

/ Optimization

The optimization problem was set-up as follows;

Objective: Maximize efficiency over duty cycle
Constraints:

- Base torque greater than 180Nm
- Base speed greater than 50,000 rpm
- Automate any modeling and simulation tool
- Integrate these tools together to create repeat-able simulation workflows

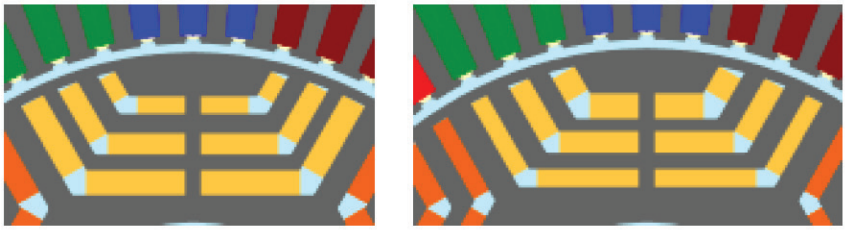


Figure 5. Results for Design Optimization

The optimum design was identified less than one hours later;

	original	optimum
Efficiency (%)	70,9	73,7
Base torque (Nm)	191,9	181,5
Base speed (rpm)	6036	6226

Table 1. Efficiency Results for Optimum Design

In this particular case, we were able to increase the efficiency of our motor by 3% while meeting all of our constraints in less than one hour.

Model-Based Systems Engineering

To manage the rapidly increasing complexity of products, many engineering organizations across multiple industries are embracing model based systems engineering (MBSE) to be able to make informed decisions very early in the design process, understand how decisions made for one system will impact other systems and the overall product, and manage trade-offs between performance, cost and requirements.

When MBSE models that capture architecture, behavior and requirements of a product are available, ModelCenter acts as the bridge between these MBSE models and the simulation models that are used to evaluate a particular design and check whether the requirements are met. This integration allows engineers to benefit from engineering simulation models earlier in the design cycle, at the architecture definition stage. It provides systems engineers with the ability to run trade studies and gain insight into their design process by identifying very early on which of the requirements might be constraining the design and which architecture or design variables are the most important to manage carefully. It also breaks down the silos between engineering disciplines by bringing them into the same MBSE model and ensuring that all the engineering models reflect the same instance of the design.

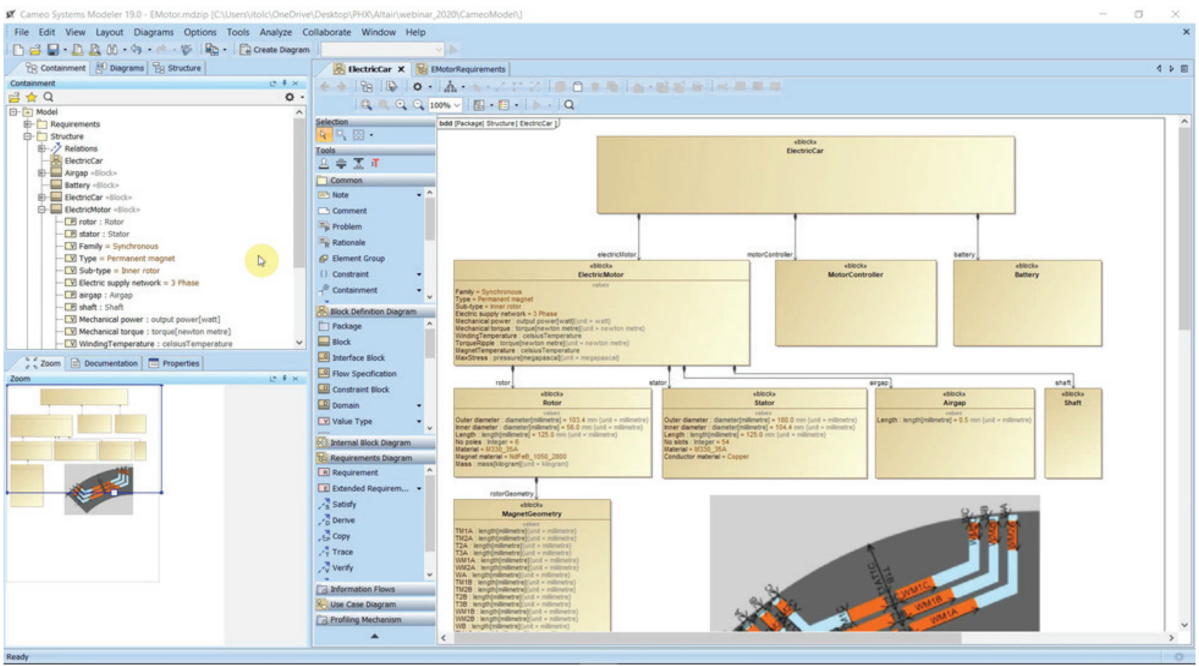


Figure 6. SysML Model of E-Motor Block Diagram Describing E-Motor Components & Their Relationship

The block diagram captures information about the e-motor design and in particular the magnet geometry and its properties, which are the inputs into the e-motor simulation workflow we reviewed earlier. In the first direction of our bi-directional connection between SysML models and simulation models, ModelCenter MBSE will leverage the authoritative source of truth that is this SysML model and update the simulation workflows to reflect the architecture and design parameters defined in the SysML model.

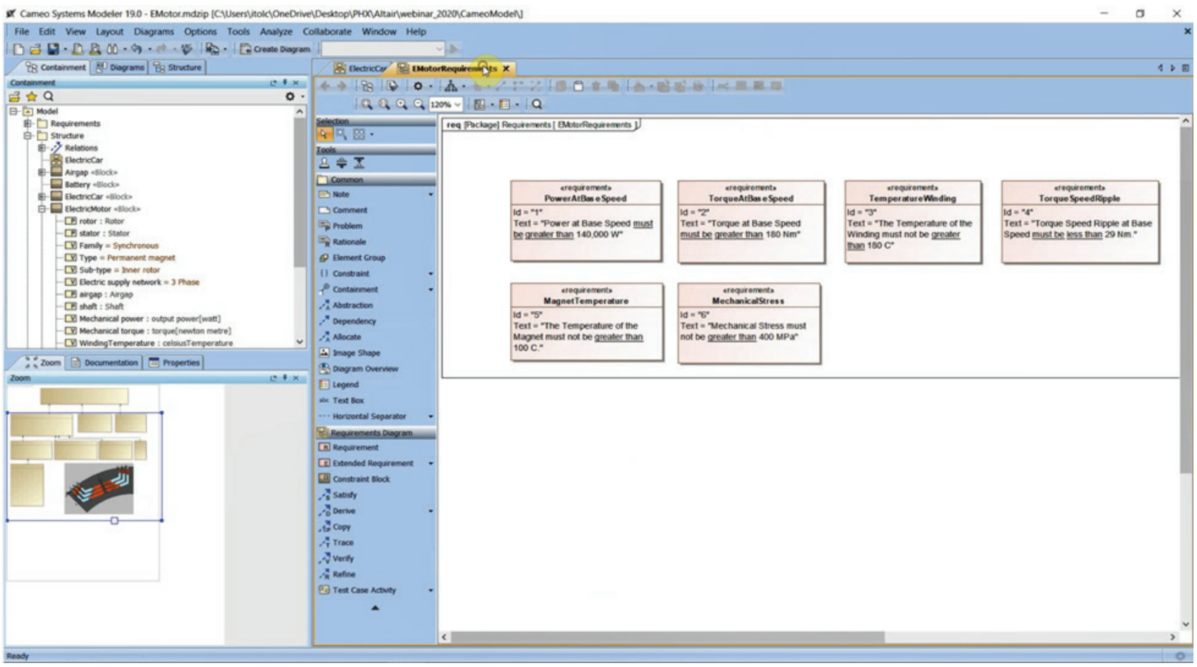


Figure 7. E-Motor Requirements Diagram

In the second direction of our bi-directional connection between SysML models and simulation models, ModelCenter MBSE will bring back simulation results into the SysML model so they can be compared to these requirements – this comparison is shown in the table below:

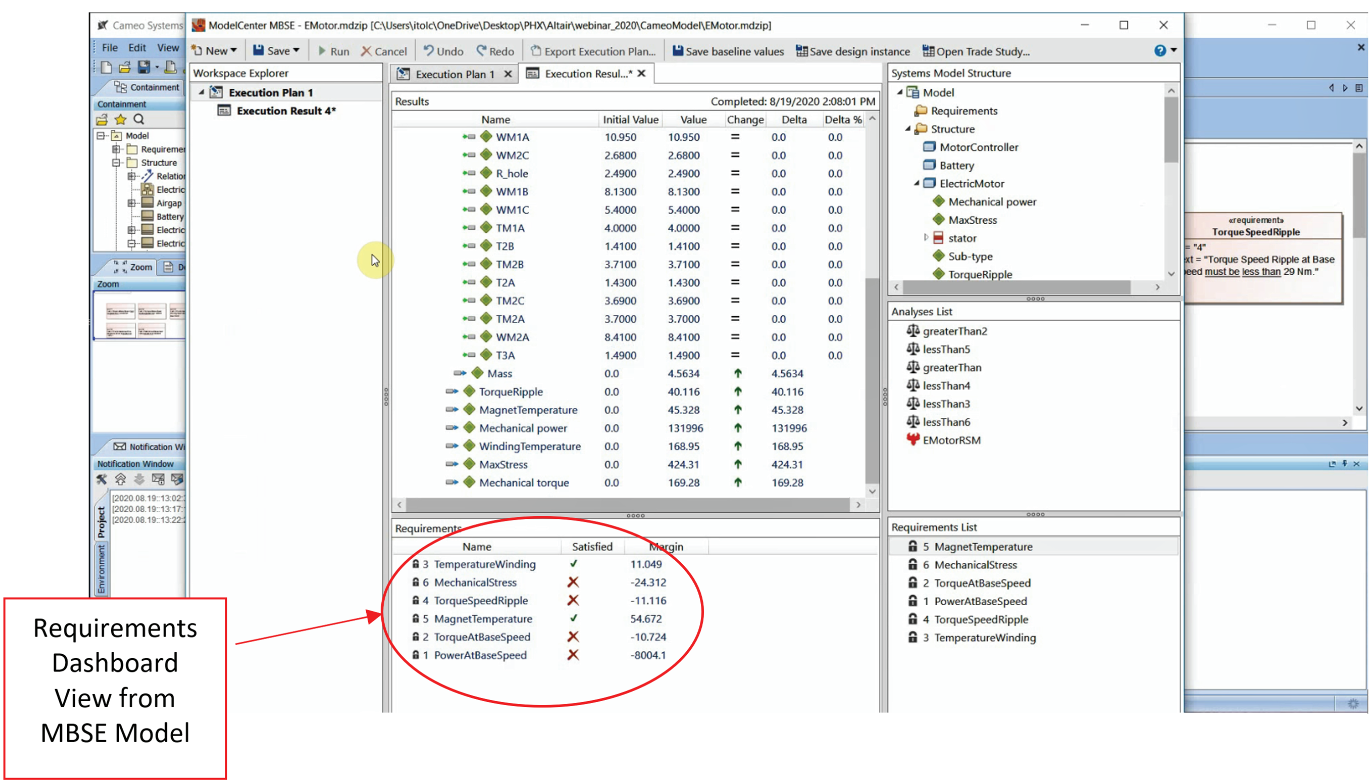


Figure 8. ModelCenter® MBSE showing Requirements from MBSE Model

Phoenix Integration, Inc.,
An Ansys Company

Phoenix Integration Blacksburg
1715 Pratt Drive
Suite 2000
Blacksburg, VA 24060
U.S.A.
540.961.7215
modelcenter-sales@ansys.com

ModelCenter® is the environment for Model Based Engineering.

ModelCenter® is a vendor-neutral software framework for creating and automating multi-tool workflows, optimizing product designs, and enabling Model Based Systems Engineering (MBSE). It is used by leading organizations worldwide to reduce development costs, improve engineering efficiency, stimulate innovation, and design more competitive products. Successful applications can be found in multiple industries, including aerospace, automotive, defense, electronics, energy, heavy industry, and shipbuilding.

Visit www.phoenix-int.com for more information.

Any and all ANSYS, Inc. brand, product, service and feature names, logos and slogans are registered trademarks or trademarks of ANSYS, Inc. or its subsidiaries in the United States or other countries. All other brand, product, service and feature names or trademarks are the property of their respective owners.

© 2021 Phoenix Integration Inc. & ANSYS, Inc. All rights reserved