INNOVATIVE MOTOR DESIGNS FOR ELECTRIC CARS COME TO LIFE

Faraday Future designs motors for electric cars.

By **GEMMA CHURCH**

THE AUTOMOTIVE INDUSTRY IS IN THE MIDST OF A DISRUPTION, and the transcendence of electric vehicles from niche to mainstream is a driving force behind this change.

Challenges remain to improve the motor designs used in electric vehicles. One potential solution is the use of power magnetic devices (PMDs), a category of devices that includes motors, generators, transformers, and inductors. In simple terms, these components utilize an electromagnetic field to convert electrical energy to mechanical energy, or vice versa.

In the field of power engineering, and particularly in the design of PMDs, modern advances are targeted at reducing system losses, mass, volume, and cost, while simultaneously increasing power capability, reliability, and large-scale manufacturability.

MODELING, OPTIMIZATION, AND COLLABORATION COME TOGETHER

ACHIEVING THESE COMPETING OBJECTIVES in modern applications requires advanced methods to optimize the design of various PMDs such as electric motors. These include computationally efficient device models in conjunction with state-of-the-art optimization techniques. Furthermore, the design constraints pertaining to electric motors represent a complex multiphysics problem from a mechanical, electrical, and thermal perspective.

Faraday Future, a start-up technology company focused on the development of intelligent electric vehicles, is using COMSOL Multiphysics® software, a multiphysics finite element analysis program, to produce cutting-edge electric motors with high power density.

The organization is also taking an innovative, modular approach to electric vehicle design. Omar Laldin, lead electromagnetic engineer at Faraday Future, explained: "My group develops motor designs for a generic set of vehicles, primarily suited to our variable platform architecture, which allows for modular development of electric vehicle powertrains. We can add or remove motors, adjust battery quantities, and collapse or increase the size of the chassis.

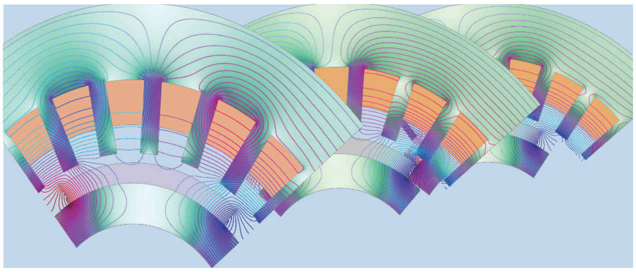

Figure 1. Finite element analysis (FEA) of a nonlinear-surface permanent magnet synchronous motor (PMSM).

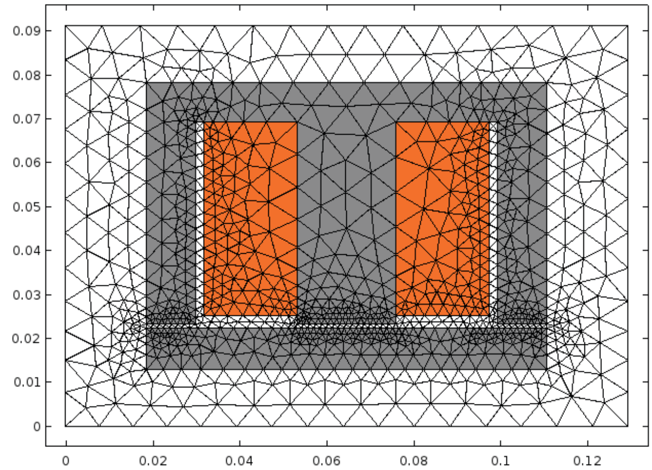

Figure 2. Mesh of the EI-core actuator.

"To be able to do that, we have to design the motor for a variety of conditions, and need to take into account several different aspects of the motors beyond just the electromagnetic components, such as the mechanical and thermal behavior," Laldin added. Figure 1 shows an example of an electromagnetic analysis conducted by the group.

This involves completing a series of advanced optimization algorithms, which quickly model how particular designs will behave. Speed is of the essence, as these optimization algorithms are required to perform numerous iterations to ensure a variety of designs are investigated. As a result, some aspects of the models need to be simplified.

Laldin explained: "It could take several weeks to do a full CFD analysis to predict thermal behavior. There are often thousands of designs to be considered and hundreds of operating points for every given design, making it impractical to do detailed multiphysics analysis with a very computationally heavy tool. Tools like the COMSOL® software, which allow us to conduct thorough electromagnetic

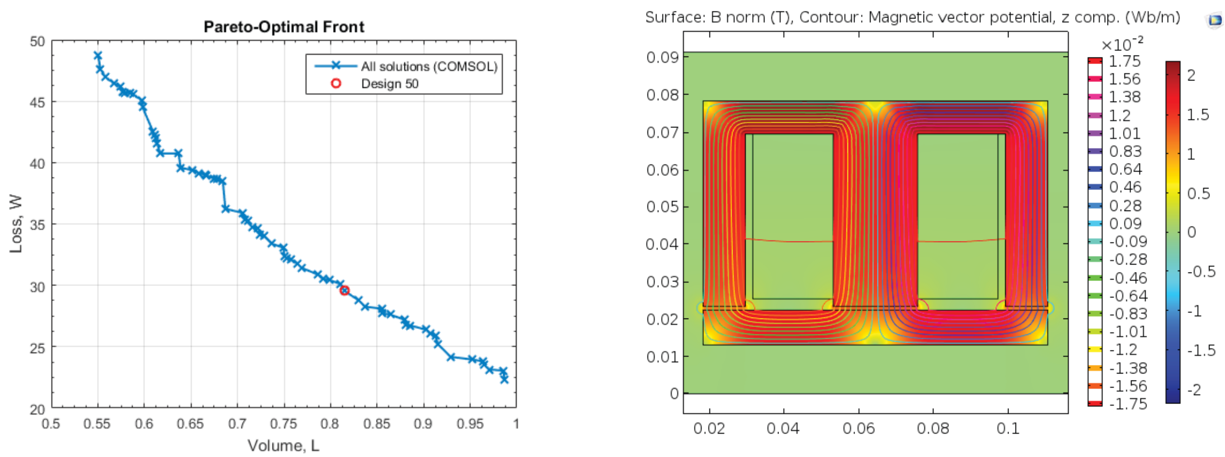

Figure 3. Left: Pareto-Optimal Front providing mass vs. loss tradeoff. Right: Magnetic flux distribution in the EI-core actuator.

and mechanical analyses along with simplified thermal analysis, work in a very stable way and give us quick feedback on each of these aspects during the design process."

The versatility of COMSOL also helps the Electromagnetic Motor Design Group collaborate with the other teams within Faraday Future, including Motor Mechanical, Inverter, Motor Control, Powertrain Control, Systems Engineering, and so forth. Collectively, these groups form the Powertrain Group within the organization.

"We do all the early stage analysis before we send data to other teams to make sure we're in the right ballpark, and that limits the number of iterations we have to do with other teams. I think that's one of the most beneficial aspects of the COMSOL simulation and modeling tools," he added.

DESIGNING AN ACTUATOR

THE EM TEAM DESIGNED an EI-core actuator to meet certain constraints, while obtaining a compromise between competing volume and power loss objectives. While the power loss must be minimized, they did not want to increase the size of the component to do so, as package size is a critical metric in most vehicular systems. The actuator was made up of a coil of conducting wire wrapped around a stationary E-core, along with a movable I-core (Figure 2).

They performed a 2D electromagnetic field analysis in COMSOL®, coupled with a genetic algorithm implemented in MATLAB® software. The model accounted for the highly nonlinear behavior of the various steel materials, while the genetic algorithm provided the globally optimized and multi-objective Pareto-Optimal Fronts, which provided the tradeoff between reducing the volume and power loss (Figure 3).

They used geometric parameters of the actuator as inputs in the algorithm and obtained losses based on the coil resistance. This allowed for the rapid investigation of numerous designs of the electromagnetic actuator, capable of delivering 2500 N of force.

> "COMSOL was a very natural choice for us, as we are developing state-of-the-art technologies and appreciate the need for speed.
>
> — OMAR LALDIN, LEAD ELECTROMAGNETIC ENGINEER, FARADAY FUTURE

INVESTIGATING LOSSES

THE TEAM INVESTIGATED the nonlinearity of the steel used in electric motors, which changes the nature of high-frequency conductor losses in a slot. These losses increase at high speeds due to the increase in skin and proximity effect in the conductors; they are also affected by the temperature. Due to the geometry of the motor, some winding architectures and their conductors are more easily cooled than others. For example, the spacing of the conductors and their dimensions can affect the heat transfer in the slot.

Laldin and his colleagues performed further multiphysics analysis, coupling the electromagnetic components with the thermal behavior to identify hotspots in the motor that could cause catastrophic failure. They discovered that the current density within the conductors changed significantly due to changes in flux density across the slot. They calculated the loss density in each of the conductors and then obtained the temperature distribution, which provided the maximum hot spot temperatures in different areas of the motor (Figure 4).

Laldin said: "The loss in different conductors can vary even if we have the same current. We model these variations and do some

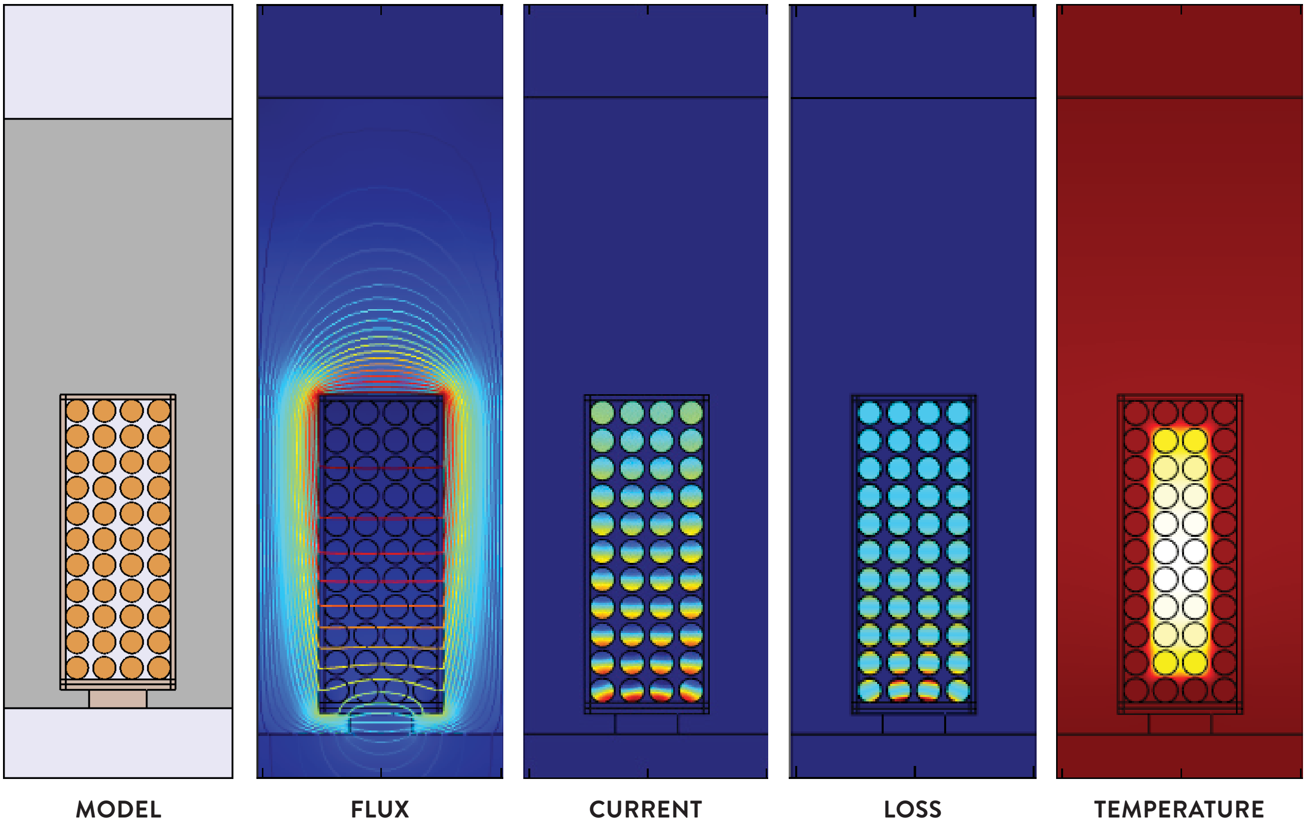

Figure 4. Left to right: Model geometry, magnetic flux, current density, power loss, and temperature distribution in a model of a stator slot.

approximate and quick thermal analysis in COMSOL, which allows us to study the temperature distribution."

Identifying the maximum hot spot temperatures enables manufacturers to determine the reliability of the design and prevent destructive motor events.

This multiphysics approach brings further time savings to Faraday Future, as one person can both design and analyze a motor and/or its components. Laldin said: "Instead of doing 10 iterations with the various teams, our tools allow us to complete the design in 1 to 2 iterations. This is one of the biggest advantages of having a multiphysics analysis tool — we can cut down on the number of iterations we need to do between different groups. It's a lot quicker for one person to optimize the design, followed by minor refinements across the teams, than it is for each team to independently analyze each aspect of the physics."

» *APPLICATION EXCHANGE FOR THE FUTURE*

FARADAY FUTURE IS A RELATIVELY young company, yet it has achieved great strides in the electric vehicle sector as they designed, developed, and constructed a working electric vehicle within just two years. The organization has embraced COMSOL's Application Exchange, an online community where users can upload and share their models and discuss techniques and findings with other users, to help fuel this growth. Laldin said: "The only realistic way to achieve such innovation is to utilize the experience of our suppliers and the capabilities they have. In a user community, it's a lot easier to find solutions for problems that we all have in the field."

Laldin added: "COMSOL was a very natural choice for us, as we are developing cutting-edge technologies and appreciate the need for speed. For example, if I need a new feature in the software, the company is very responsive in including that feature in the next release."

The open and dynamic Application Exchange platform will also help Faraday Future stay ahead of the competition, as Laldin added: "On top of that, fostering this online community fits with the start-up mentality, where you're willing to contribute non-sensitive data and know-how in an open exchange for the benefit of everyone involved. I have always felt that you get more out of user communities and the exchange than what you put into them, especially when it's backed by a state-of-the-art industrial partner. It's a very good combination for a company like ours." ◎