Electric car

ELECTRIC VEHICLES ARE NOT ALWAYS AS QUIET AS YOU THINK!

RWTH Aachen University team employs SIMULIA solutions to develop drivetrain simulations that assess noise and vibration

You've likely been caught by surprise when you're out walking and an electric car drives up behind you. A light hum, and perhaps the soft crunch of tire on pavement, is all you hear. There's certainly a lot less external noise than an internal-combustion vehicle would make.

But the irony of the electric vehicle (EV) is that the quietness of its machine allows the driver and passengers to hear more of other noises happening inside the car. Rattle, squeak and vibration, which the sounds from an internal combustion engine (ICE) might mask, become more apparent in an electric car. What's more, that distinctive EV hum can become amplified throughout the car at certain speeds—to noticeably annoying levels.

So what's an automotive engineer to do? For one group of researchers at Germany's RWTH Aachen University, the answer is to use simulation and systems engineering to uncover hidden sources of EV noise and explore ways to mitigate them.

HUNTING DOWN THE CAUSES OF EV NOISE

RWTH Aachen Ph.D.-candidate Pascal Drichel presented the latest findings of his engineering team (Mark Mueller-Giebeler, Markus Jager, Joerg Berroth, Matthias Wegerhoff, Johannes Klein, Sebastian Rick, Georg Jacobs, Kay Hamayer and Michael Vorlander) at the Simpack 4th Wind & Drivetrain Conference in Hamburg, Germany earlier this year. The group is focusing on developing methods and models for the analysis, optimization and assessment of the noise and vibration (aka NVH) behavior of vehicles. SIMULIA solutions are key tools for them as they perform FEA and multi-body simulations; they also carry out on-site measurements for parameterization as well as validation of their component, assembly and system-level models.

Drichel is team leader of the NVH group of the drive technology department/division at the Institute for Machine Elements and Systems Engineering (MSE) in the University's department of mechanical engineering. When he came to the Institute

> "From the research point of view, we like the combination of state-of-the-art nonlinear solvers, well-proven modeling element libraries that are continuously getting better and wider, and the user-routine capability...."
>
> — Pascal Drichel, Ph.D.-candidate, RWTH Aachen

almost six years ago, he already had a good bit of simulation expertise under his belt. "I started working with both Abaqus and Simpack more than ten years ago," he remembers. "When I began my studies in 2007 I used the software as a student worker in the Institute, doing dynamic simulations, and was also an intern at one of the big german automotive OEMs working on whole-vehicle simulations for electrical drives."

This kind of intern/OEM relationship is available to motivated students at RWTH Aachen. The University has a philosophy of close collaboration with a variety of key industries and, in the case of the MSE Institute, liaises with wind turbine manufacturers (who are understandably also interested in drivetrain technology) as well as automotive ones. The benefits go both ways: In Drichel's team's current study, partnership with the leading german drive technology companies, bundled in the research association for Power Transmission Engineering (FVA) provides real-world data to compare with the engineers' models.

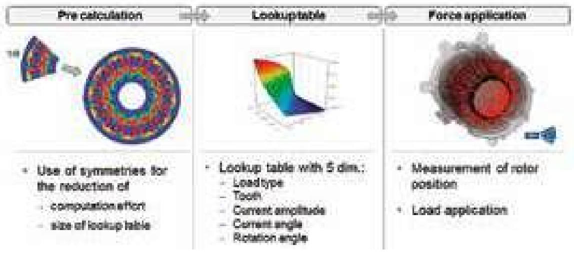
It's a work in progress, notes Drichel. "Increasing electrification in all vehicle classes, such as the e.Go, the VW E-Golf and the Tesla Model 3, keeps bringing to light new challenges regarding NVH behavior," he says. "Virtual product-development methods are becoming very helpful in addressing these, and we are working to further refine tools for the assessment and optimization of different drivetrain variants."

THE DRIVETRAIN DID IT

Why is the drivetrain, which is the group of components that deliver power to the driving wheels , the main focus of the Aachen team's work? Because it's critical to sound control: No matter how quiet the electric machine itself is, the transfer of tonal excitations from it through the transmission, differential, shafts, axels and so on to the car interior results in vibration and other noise-producing conditions that may need to be mitigated in an EV.

"Dealing with drivetrain-related NVH phenomena is a challenging engineering task," says Drichel." You're working within a highly complex system that usually involves different multiphysics domains." To understand the full scope of potential noise-generators in the drivetrain, Drichel's group is using an multi-domain hybrid approach consisting of simulation and measurement components that looks at electrics, structural dynamics and acoustics, where a central part is the multi-body-dynamics model of the drivetrain.

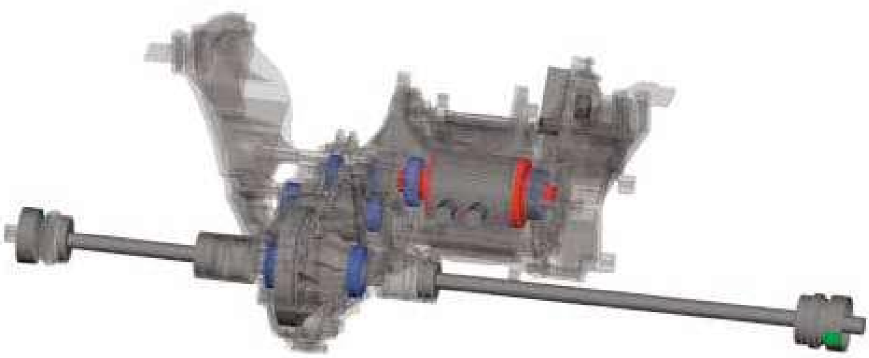
Electromagnetics: The group is developing models that describe exciting forces in an inverter-fed electrical machine. This involves both analytical and numerical modelling approaches for computationally efficient force calculation. Analytical modelling is supported with data from excitation tables and conformal mapping, while numerical modeling uses the Finite Element Method. The force-excitation spectra are analyzed to determine which effects are most dominant and should be focused on for efficient further processing.



Electromagnetics analysis.

Structural Dynamics: The team has created their own user routine for applying the previously determined electromagnetic forces to the drivetrain. Their Abaqus FEA models of drivetrain subassemblies include full flexible housings and shafts. The submodels are brought together inside a Simpack multibody simulation, which permits a significant reduction in the

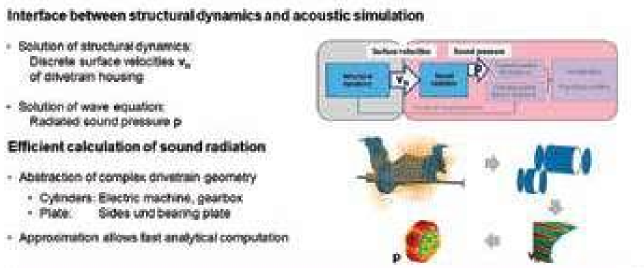
Structural dynamics analysis.



The machine and drivetrain of an electric vehicle can be the source of unique acoustics challenges.

number of degrees of freedom. This results in a highly efficient model in which many different load cases can be run quickly. Subjects of study include the transversal isotropic behavior of the stator, fluid-structure-interaction of both stator housing and machine coolant, and nonlinear bearing stiffness.

Acoustics: A complete acoustics picture of an EV must capture both airborne and structure-borne noise. Once a drivetrain simulation is set up, radiated airborne sound from the entire powertrain can be computed using an in-house acoustics tool. This is extrapolated to auralization of the car cabin noise using transfer-path synthesis. Resonance effects within the system can be studied at different machine speeds and adjustments made in the mechanisms that cause excitation and excess sound. Objective as well as subjective evaluation of the resulting "ear signals" can be carried out to evaluate how changes to drivetrain geometry affect overall noise levels in a particular EV car design.



Acoustics analysis.

SIMULIA SOLUTIONS ARE KEY TO THE SEARCH

"In much of this work, Abaqus and Simpack are common tools for us," says Drichel. "From the research point of view, we like the combination of state-of-the-art nonlinear solvers, well-proven modeling element libraries that are continuously getting better and wider, and the user-routine capability—which is a very strong feature as it allows us to incorporate our own ideas for sub-analyses into the software."

Most recently the team began using Isight for process automation and optimization as well. "In the first phase of this three-year project we didn't use Isight and it was a real pain bringing everything together manually," says Drichel. "In the second phase we decided to make everything more automatic with Isight. Now we can bring different software workflows together, which is especially important here in our environment because we have so many domains to analyze."

Multi-body, multi-scale simulation and process automation give product developers the ability to quickly gain greater insight into a system while in the process of designing it, Drichel points out. "Modern methods allow a holistic approach to system simulation of EV powertrain design that allows the identification, understanding and development of solutions for specific engineering problems that are characterized by the interactions of components and subsystems.

"It's an interesting challenge to deliver tools and models that put the sound engineers in the position of shaping the drivetrain-noise-DNA of electric vehicles," he says. "This kind of capability is very important for the automotive industry—they can spend more time working on developing their cars instead of putting workflows together!"

ANSWERS AID AUTOMOTIVE ADVANCES

Pyschoacoustics.

OEM partners are certainly interested in these kinds of results. "With the 'hybrid multi-domain toolchain' we've developed, the automotive industry will be able to do "hot spot" analysis that lets them identify resonance effects at particular speeds," says Drichel. "This in turn helps them optimize vehicle interior sound that's caused by the electric drivetrain, making EVs more pleasant and more attractive to potential buyers."

The Institute team's next research goals are twofold: first, to increase model fidelity in all domains to achieve even better correlation between measured and predicted quantities. And second, to balance result quality and computational time to analyze different model fidelity levels using "psychoacoustic" metrics, attuned to the human user's perceptions of sound. Subjective assessment of sound is a complex challenge, because it is dependent on loudness, sharpness and tonality, inter alia—all of which vary according to where within a vehicle the sound is coming from.

Drichel clearly enjoys the complexities of his team's project—but does he have an electric vehicle of his own? "I'd love to have an EV, but it's a bit too expensive for me right now," he says. In the meantime, as a self-described "passionate driver," he rides to work in a vintage BMW M3 series E46. "It's a nice car," he notes with pride. It certainly sounds like the research Drichel and his colleagues are conducting at RWTH Aachen will help make the EVs of the future quieter and more affordable for everyone.

From left to right: Mark Müller-Giebeler (ITA), Pascal Drichel (IMSE), Markus Jaeger (IEM).

For More Information

www.rwth-aachen.de