ELECTRIFYING THE COMPETITION

Top Italian university race car team revs up its motor design with the power of electromagnetic simulation.

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From its 2005 launch by 10 engineering students at Politecnico di Torino, Squadra Corse has designed and built a race car each year to compete in Formula SAE events that are organized by SAE International (formerly the Society of Automotive Engineers). In the grand tradition of Italian motorsport teams, the group's vehicles feature the classic *rosso corsa* racing colors; they have steadily shown improvements in competition results. In 2012, the team switched from the internal combustion engine category over to the full electric category and achieved a number-seven worldwide ranking through the strength of performances at events in the UK, Hungary and Italy. Participating in these competitions gives team members the opportunity to experience a true motorsport environment, comparing themselves with other teams and allowing a huge exchange of knowledge and competencies.

The present Squadra Corse group comprises about 50 students from 12 different nations who work in three divisions, including sporting direction, mechanical, and electric and electronic divisions. The 2013 vehicle underwent several innovations, including a new carbon-fiber monocoque, or unibody, construction. The two interior permanent magnet (IPM) synchronous electric motors used for the 2013/2014 vehicle were provided by team sponsors. However, these motors are not ideally suited for SAE competitions since each is rated for 60 kW of power (120 kW combined), and the rules limit the output power to 85 kW. Because the car carries a lot of unused load, the team's electric and electronic division is hard at work enhancing the motor design in preparation for the 2015 competitions. It has added simulation software from ANSYS into its engineering analysis process.

Squadra Corse's 2013 electrically powered competition vehicle, the SCR

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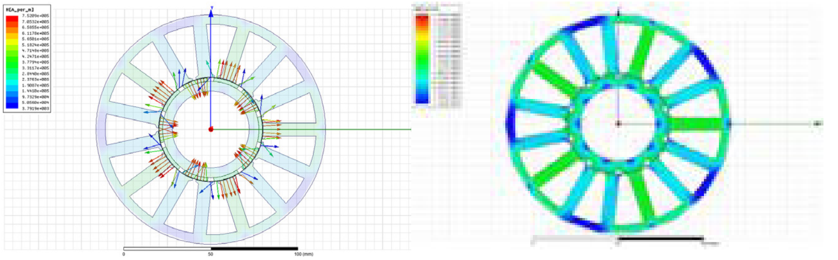
The team performed electromagnetic simulations with ANSYS Maxwell on designs that incorporate a new surface permanent magnet (SPM) synchronous motor. The permanent magnets are attached to the surface of the rotor, whereas an IPM setup has magnets embedded in the rotor. ANSYS tools made it easy to create different geometries and simulation sets by allowing a complete parametric approach. Squadra Corse has been able to easily vary every geometric dimension of the motor, including axial length, rotor and stator radii, and dimensions of the stator teeth and shoes that contain the windings. For a given geometry, the team has used Maxwell for three different kinds of simulations, including magnetostatic analyses, with and without excitations, as well as transient analysis to simulate the motor's working conditions.

At the outset, Squadra Corse performed a magnetostatic analysis without excitations, meaning that there was no current being passed through the stator windings. This allowed for evaluating the magnetic field strength and flux density produced by the surface permanent magnets along with the predicted cogging torque of the motor. Cogging torque, a form of torque ripple, is an undesirable effect that can cause stuttering at low speeds; it can be mitigated by a combination of modifying the layout of the stator, adjusting the location of the rotor magnets, or modulating current using the control electronics.

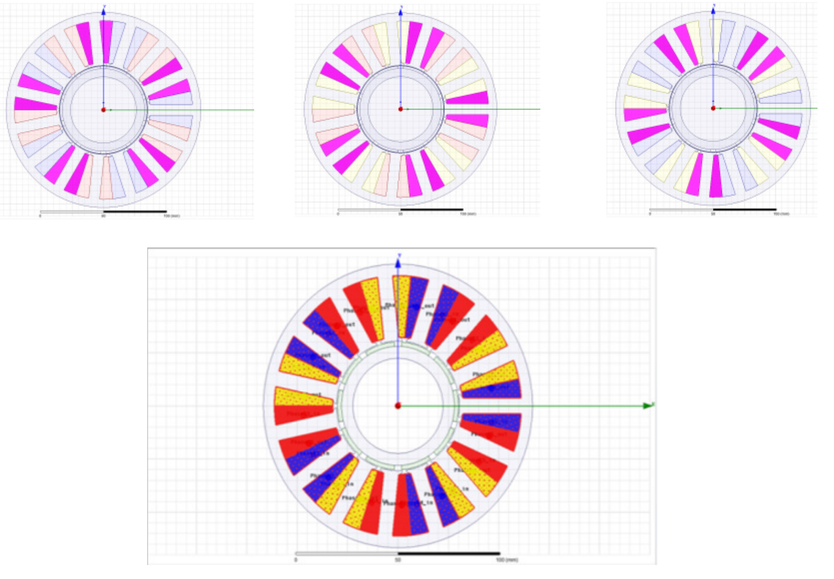
Performing a second magnetostatic analysis, the team considered the case of static excitations in the windings. These excitations are the current required to support the load that such a three-phase AC electric motor typically needs. Through this analysis, the team calculated the maximum torque that could be obtained along with the inductance matrix to be used when implementing the control system that drives the motor.

Finally, Maxwell's transient analysis capability made it possible to predict the magnetic vector potential (*A*, in webers per meter), magnetic flux density (*B*, in units of tesla) and magnetic field vector (*H*, in amps per meter) under realistic working conditions. Results for a studied design with 15 stator slots and 10 rotor magnets showed a torque ripple, or variation over one revolution, of about 6 percent. This is caused by a mismatch between the sinusoidal feed currents and a non-sinusoidal electromotive force (EMF) in the air gap between the rotor and stator. Such behavior is typical for uniformly distributed windings. Through an inverter, the control system will be responsible for creating square waveform currents, which will turn into trapezoidal waveform EMF and reduce the torque ripple.

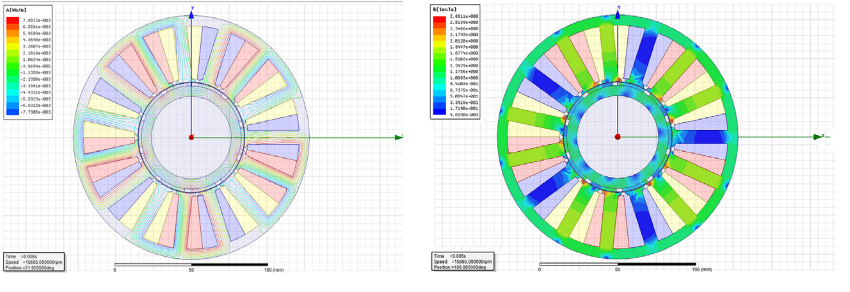
Performing multi-domain simulations through ANSYS Workbench is important to the team in further improving the car's performance. The team plans to conduct structural and fluid analyses in the coming years as it seeks to advance its legacy of excellent Formula SAE results.



Magnetostatic analysis without excitations. The magnetic field vectors (left) are shown in the air gap between rotor and stator, with the radial direction of the field alternating for each of the 10 rotor surface magnets. The contours of magnetic flux density (right) show that the flux saturates at the value imposed by the magnets (in green) and is greatest in the paths with least magnetic reluctance, which is desired for SPM motors.



Magnetostatic analysis with excitations. The excitations are applied as currents (top, left to right) with the three phases highlighted separately in pink. The sequence used for the phases (bottom) is yellow, followed by red then blue. Every winding coil enters from one stator slot and exits from the adjacent slot, so every slot houses two phases.



Analysis of transient operating conditions. The magnetic vector potential, or flux lines (left), and magnetic flux density (right) are shown for motor speed of 15,565 rpm. The flux density is higher in 10 stator teeth (in green) and saturated in edges of stator shoes (lower right of stator teeth, in yellow, orange and red).

Learning and Making Engineering Fun
Every year, students around the world use simulation in engineering competitions that are not only fun but also prepare them for future careers.