Application Brief

Advanced Design of Electric Machines Using the ANSYS Electric Machine Design Toolkit

Computation of efficiency maps is critical but can be laborious in designing an electrical machine. ANSYS offers a user-friendly electric machine design toolkit integrated into ANSYS® Maxwell. The toolkit allows for the computation and display of torque speed curves, efficiency maps and other performance curves for electrical machines.

Products Used
ANSYS Maxwell, ANSYS Optimetrics™, ANSYS RMxprt™ (optional), DSO (optional)

Keywords
Permanent magnet synchronous machines, efficiency mapping, torque speed curves

Electrical Machine Design Flow
Predicting efficiency maps in the design stage of a traction motor is a crucial development for optimal operation of hybrid electric vehicles (HEV/EVs). The designer must ensure that the motor produces optimal efficiency in the speed range and road-load profiles during drive cycles.

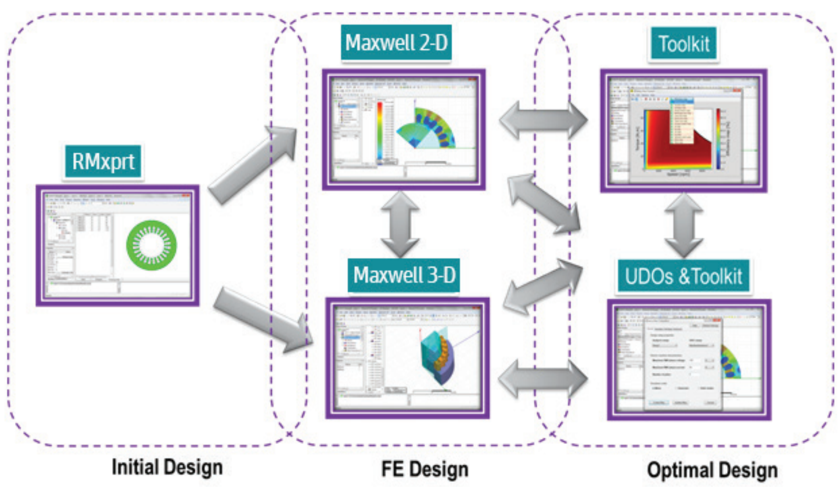

Figure 1. Design flow for electrical machines using ANSYS Maxwell

ANSYS offers a toolkit for computation of the efficiency map in a permanent magnet synchronous machine using a customized script to control the Maxwell finite element (FEA) software. The workflow is shown in Figure 1. ANSYS RMxprt, which is an analytical tool used to narrow the design space and automatically generate the Maxwell 2-D/3-D model, is optional. Maxwell 2-D/3-D is employed to achieve the final design of the motor, while the toolkit is applied to automatically generate optimal performance maps.

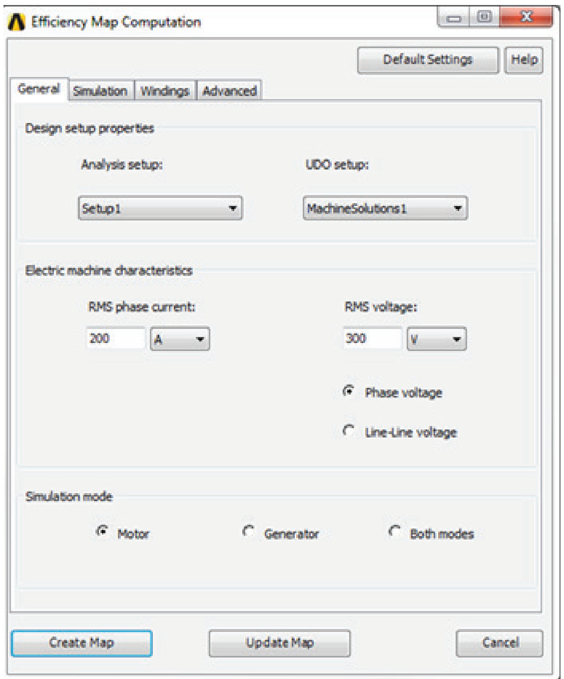

Figure 2. Toolkit interface for efficiency map computation used in ANSYS Maxwell

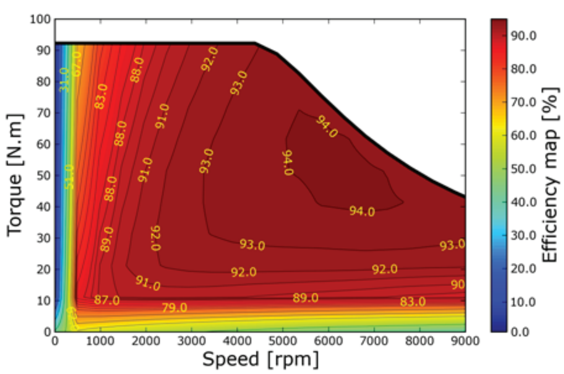

Figure 3. Simulated results of efficiency map in interior PM motor

Electrical Machine Design Toolkit

An efficiency map can be created by taking measurements in a test environment of the output torque, input power and output power. Of course, this means that the traction motor first must be designed and manufactured. And at this late stage of the design cycle, making design changes to improve performance is costly and takes another round of prototyping.

The method used to calculate the efficiency map for interior permanent magnet (IPM) machines is based on the maximum torque per ampere unit (MTPA) strategy. At a given operating condition of torque, speed and DC bus voltage, the trajectory of the current is crucial to optimize efficient operation of IPM machines. Other important factors include the pulse width modulation (PWM) method and switching frequency. In theory, by varying the input voltage supplied to the IPM machine, there can be an infinite number of control current combinations that produce the required torque at a given speed. Therefore, the control strategy needs to be carefully implemented to minimize losses in the motor and, thus, increase efficiency. Using optimization routines, the optimal operating condition is found for the entire torque-speed curve, and the efficiency is calculated from transient 2-D/3-D FEA simulations.

The ANSYS toolkit generates performance curves and efficiency maps automatically. It computes and displays torque speed curves and efficiency maps for an arbitrary PM synchronous machine, in motoring mode, generating mode or both. A list of output quantities are automatically produced — such as efficiency, electromagnetic losses, power factor, L_d, L_q, etc. The toolkit is capable of leveraging multiple CPUs to solve the parametric sweep and significantly reduce simulation time.

Toolkit Application at Magna Electronics

Electric machines include materials whose cost can vary drastically over a relatively short period of time due to market demands and a limited raw materials supply. Traction motors used in HEV/EVs utilize rare earth permanent magnets. Changing a design parameter, such as the shape or size of the magnets, most likely will impact performance (such as a reduction in efficiency) or introduce a change in torque quality. Engineers who design interior permanent magnet machines most often create a 2-D plot of the efficiency and torque of the machine versus its rotation speed, known as an efficiency map. The goal is to reduce the IPM's machine's magnet size and maintain the maximum torque and efficiency throughout the whole speed and
torque range.

Magna Electronics validated the ANSYS simulation tool through measurements. The experimental and simulation results of the efficiency map are shown in Figures 3 and 4, respectively; they are in good agreement in both magnitude and contour. The company's work resulted in reducing the permanent magnet size by 20 percent, as shown in Figure 5. The impact of the magnet size reduction on efficiency and machine performance was quantified, and design changes were simulated that maintained desired efficiency over the operating range.

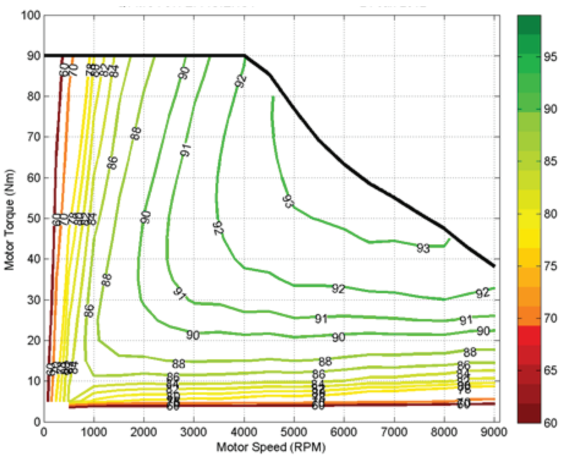

Figure 4. Experimental results of efficiency map in interior PM motor measured by Magna Electronics

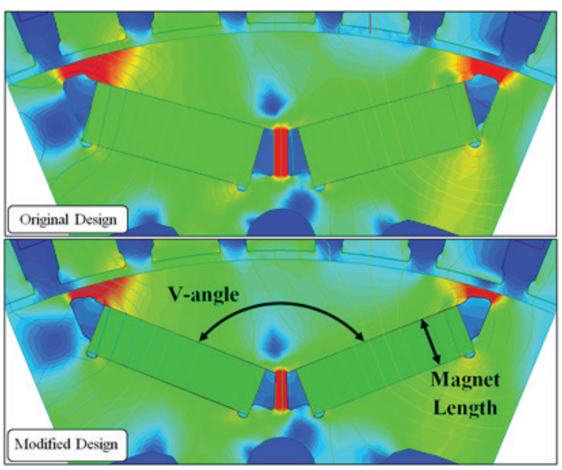

Figure 5. Original and modified designs provided by Magna Electronics. Modification included reduction of magnet length and decreased V-angle of the magnets.

Summary
ANSYS offers a simulation toolkit environment that enables seamless complex computations for design and optimization of electric machines, including performance curves and efficiency maps. The toolkit has been applied successfully in industry, and robust results have been verified.

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