WIRELESS ELECTRIC VEHICLE CHARGING— DESIGN AND ANALYSIS WITH CST STUDIO SUITE

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Increasing the use of electric vehicles is an important part of reducing greenhouse gas emissions and essential for improving air quality in cities. By the end of 2016, there were over two million electric cars worldwide—almost twice as many as there had been at the start of the year. Battery electric buses are already a staple of many Chinese cities, while electric vans are becoming a key part of postal and courier fleets.

To support the new generation of electric vehicles, a comprehensive network of charging points is needed. At present electric vehicles are usually charged with a cable, often at the driver's home. This limits the use of electric vehicles in everyday situations: returning a bus or delivery van to the depot for regular charging puts the vehicle out of use and wastes driver time.

Wireless electric vehicle charging (WEVC) offers a solution. Rather than transferring power by cable, WEVC uses electromagnetic coils buried in the road to transmit power to vehicles through inductive coupling—the same principle used in charging mats for mobile phones. However, the power requirements for WEVC are much higher, on the order of kilowatts—the system demonstrated in this article complies with the WPT 2 level, 7.7kW at 85 kHz—and efficiency and safety are key considerations when designing a WEVC.

The electromagnetic simulation tool CST STUDIO SUITE allows the performance of charging coils to be optimized early in the design process, and analyzed as part of the complete electric transmission system. The LF Frequency Domain Solver in CST STUDIO SUITE is ideally suited to this application, with realistic numerical coil models, eddy current simulation, and support for materials including lossy metals and nonlinear magnetic materials such as ferrites.

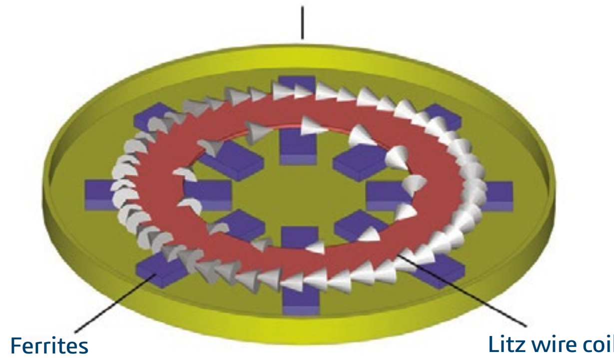


Figure 1: Coil diagram, showing the main components.

The coil shown in this article (Figure 1) comprises 12 turns of stranded litz wire with an inner diameter of 190mm and an outer diameter of 286mm on a ferrite MnZn core. For safety reasons, the coil is surrounded by a 5mm thick aluminum shield. The coils on the car and in the floor are considered to be identical, with the car coil placed directly on the underbody shield and the floor coil buried in the road (Figure 2).

One area where simulation is used is to reduce power losses. The coil needs to be shielded in order to confine the magnetic field, but eddy currents induced in the shield will cause some power to be lost. Other sources of power loss include the ferrite cores used to guide the magnetic flux to increase the coupling, the resistance of the coils themselves, and misalignments of the coils. Electromagnetic simulation can calculate these losses and allow different design configurations and material choices to be compared in order to find the most efficient combination (Figure 3).

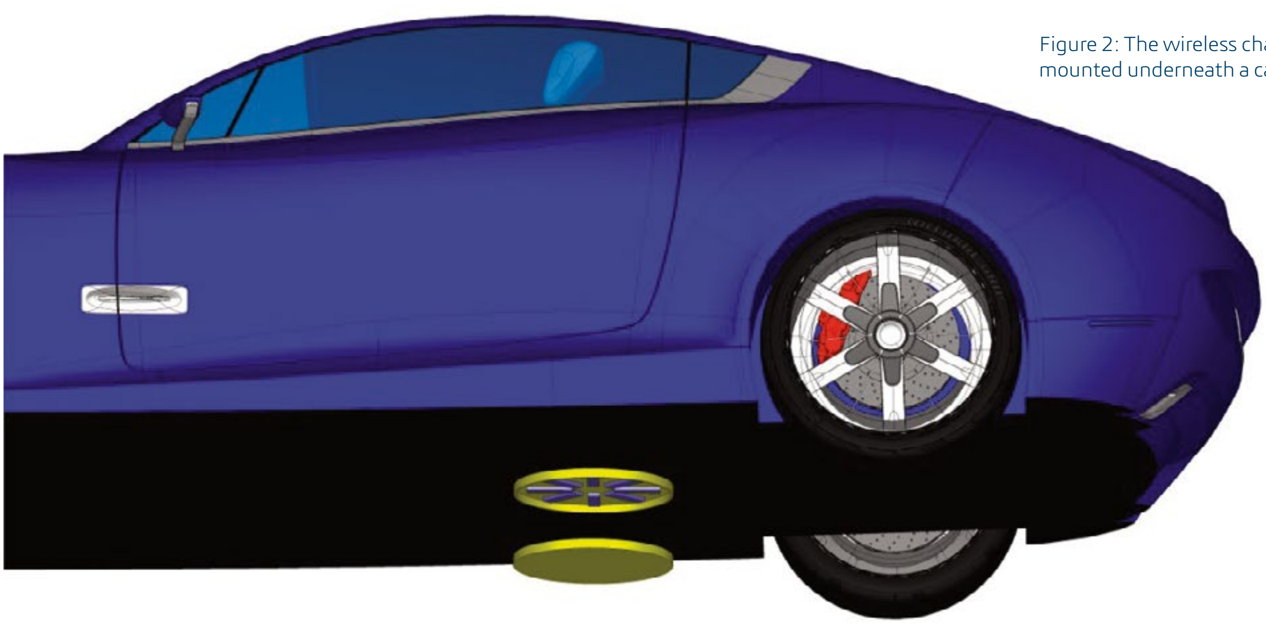
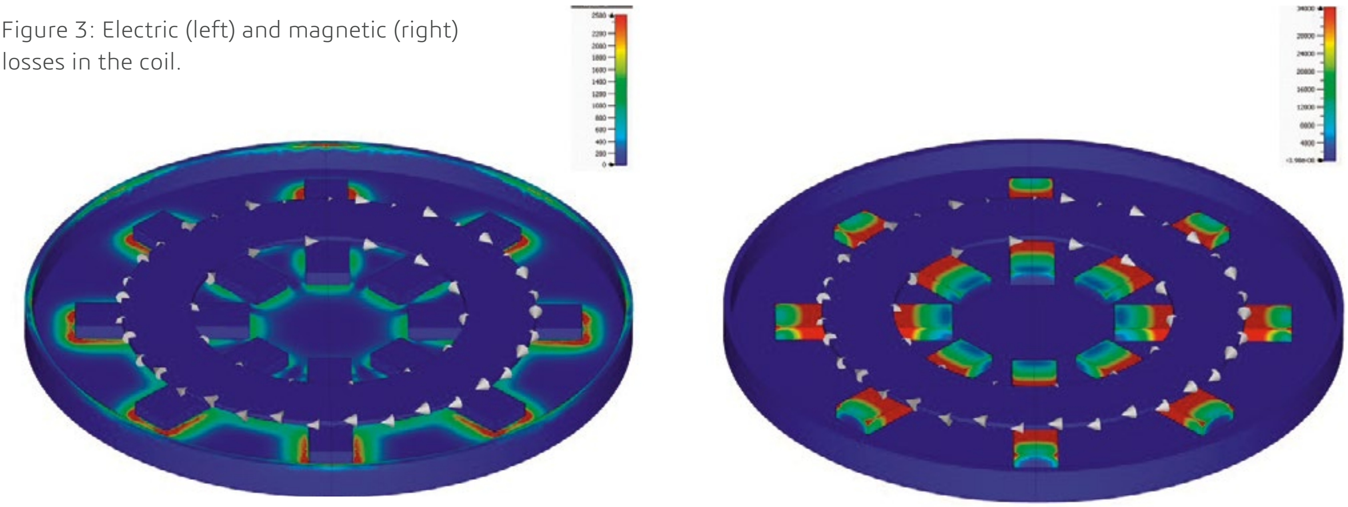


Figure 2: The wireless charging coils mounted underneath a car.

Figure 3: Electric (left) and magnetic (right) losses in the coil.



Often, the properties of the materials and the characteristics of the components are not fully known, and EM simulation can be used to extract their properties. For instance, litz wire has a complex internal structure, which reduces proximity and skin effect losses in the coil (Figure 4). With simulation, the resistance of the litz wire coil can be calculated, taking into account the realistic cross-section of the wire and the skin and proximity effects. Similarly, the losses from the nonlinear magnetic properties of the ferrite can be implemented with complex permeability to fit measurements.

One of the most important results from coil simulation is the efficiency of the coupling in order to minimize losses in surrounding materials or from mismatched coils. CST offers a tool for automatically calculating the performance of coupled coils including the maximum efficiency, the coupling coefficient between the base coil and the car coil, and the optimal load condition—the load under which the best power efficiency occurs.

Using this information, engineers can optimize the performance of the charger. In order to match the coils, WEVC systems include compensation networks. These are circuits used to tune the coils for better power transfer efficiency. The direct link between circuit simulation and full-wave 3D simulation in CST STUDIO SUITE allows the compensation network to be created alongside the 3D model and optimized to reach optimal load impedance and reduce power losses further.

The performance of inductively-coupled coils will depend on their exact alignment—this is especially important for vehicles, since in many situations the coils cannot be easily lined up. With a parameter sweep, efficiency can be calculated for multiple different alignments in order to investigate how this affects coil performance and to help tune the compensation networks.

Another application of circuit simulation is for a system level simulation of the whole charging system, from the 3-phase AC power source, through the rectifiers and inverters, to the battery. The goal here is to find the duty cycle of the inverter such that sufficient DC power reaches the battery. With the full system, the real operating point can be calculated and factors such as interference and human exposure can be analyzed in a realistic scenario.

Charging is just one factor of electric vehicle design. Other related design considerations include the motors and motor controls, the cabling, the onboard electronics, and the chassis as a whole, as well as human exposure. These combine high-frequency and low-frequency electromagnetic simulation, thermal and mechanical elements, and can all be designed, simulated and analyzed with CST STUDIO SUITE and other SIMULIA tools for a more integrated workflow.

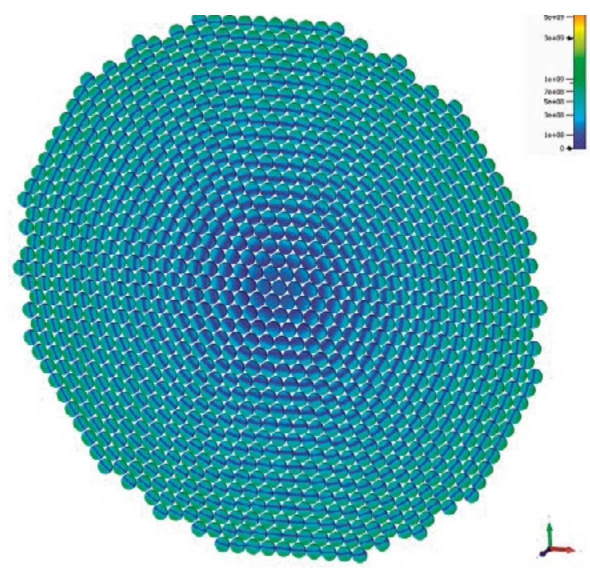


Figure 4: Current density in a short section of Litz wire, showing the skin and proximity effects.

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www.cst.com/wirelesscharging