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Novel Double-D Coil Geometry for a Bidirectional Wireless Power Transfer System

Electric vehicles (EVs) offer the opportunity to use vehicle-to-grid (V2G) technology, where the vehicle battery is utilized as a grid connected energy storage device and delivers power to the grid and local loads. In recent times, wireless power transfer (WPT) in EVs has been studied by numerous researchers due to advantages, such as convenience of wireless operation and safety of inductive power transfer. Design challenges for WPT systems in EVs include high charging efficiency, a large air gap and tolerance for misalignment. By optimizing the coupler coil geometry, the efficiency can be increased over a wide range of parking positions and ground clearances, while at the same time limiting the electrical component stress. A novel double-D coil geometry is presented to optimize the magnetic coupling and decrease the coupling variation over all parking positions. A prototype was built to verify the analysis and 3D-FEM simulations with measurements.

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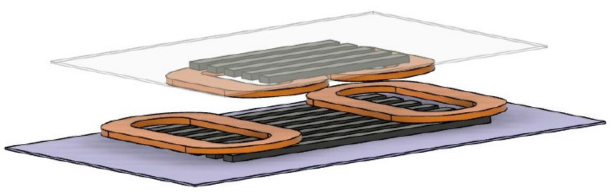
Introduction and Motivation

The key component of a WPT system is the magnetic coupler. The geometric parameters of the coupler have a strong impact on the behavior of the system. For different parking positions, as well as ground clearances, the coupling coefficient between the ground pad module (GPM) and car pad module (CPM) coil varies over a wide range. This variation causes a suboptimal design and results in additional losses. Thus, for different parking positions the magnetic coupling should be as high as possible and the coupling variation small. Starting from a standard double-D coil geometry discussed in literature, the magnetic coupling for the given GPM and CPM dimensions were simulated. The simulation results show that double-D geometries have one major drawback. The magnetic coupling variation along different misalignments, as well as ground clearances, varies over more than a factor of three.

Novel Double-D Coil Geometry

In this paper, an optimized coil geometry to reduce the magnetic coupling variation is presented. By separating the double-D windings in the center of the GPM in lateral direction, while keeping the outer dimensions of the GPM unchanged, the magnetic field distribution becomes more homogenous. This causes a reduction of the magnetic coupling for near ideal parking positions to about 25 %, but in contrast, leads to an increase for maximum misalignment. In fact, a nearly constant coupling behavior with a variation of less than 5 % over the entire range of parking positions at any given ground clearance is achieved.

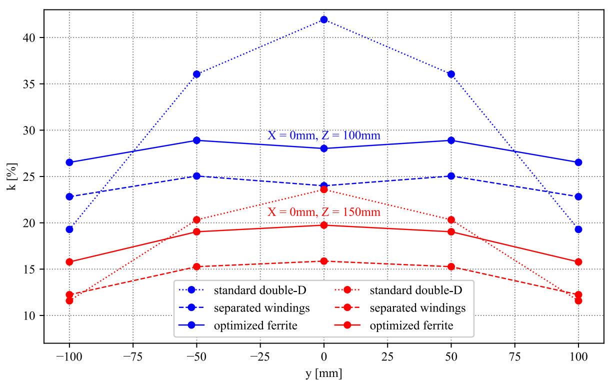


Ferrite Core Optimization

A further optimization variable was the design of the ferrite core material. Ferrite material is expensive and heavy, which are both limiting factors in the EV market. With the usage of ferrite bars, a sweet spot of magnetic coupling and weight has been found. Unlike in a circular pad, the core shape can be significantly varied in a double-D pad, considering its shape, position and relative size with respect to the shield and coil. By decreasing the length of the ferrite bars, an increase in magnetic coupling can be achieved. It can be shown that the optimal ferrite bar length does not extend beneath the outer most part of the windings. With this, the mutual flux increases, as the flux is more directly guided through the coil. Additionally, the generated leakage flux is reduced by the lack of ferrite. For the same geometric specifications as before, the coupling increases in total by approximately 4 %

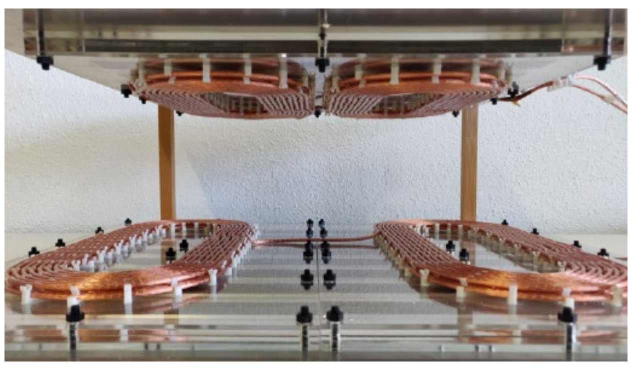
Simulation and Comparison

The simulation results of the magnetic coupling for different misalignments are shown in the graph below for the standard, the separated windings and the optimized ferrite bars design. With the new design, the coupling variation can be reduced to a minimum. At the same time, by reducing the ferrite core length, weight and costs can be saved by more then 20%.



Measurements and Prototype

For ideally positioned WPT coils, the magnetic coupling reaches a value of 25 %, whereas the worst coupling of 13 % was measured with maximum misalignment and ground clearance. The measurements show a very good agreement to the simulations with an absolute deviation of less than 1.5 % at the largest ground clearance.



Conclusion

Wireless charging technology for electric vehicles is being developed to enable an automatic and convenient charging experience. The V2G feature in WPT systems is necessary to take full advantage of the vehicle battery energy for grid purposes, especially as autonomous vehicles become more relevant. A double-D magnetic coupler is the central part that connects the EV to the grid and enables a bidirectional power flow. The new optimized coupler design provides a minimized coupling variation over all parking positions. With an optimized ferrite core design, the magnetic coupling can be increased, while at the same time weight and costs can be saved. Additionally, the magnetic stray field is smaller for this design compared to other coupler shapes. The measurement results from the prototype show a good agreement to the theoretical analysis and the simulation results.

References

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