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Influence of Coupler Parameter Variation of an Inductive Charging System for Electric Vehicles

Inductive power transfer (IPT) has grown to be an important technology in a variety of applications. For the past years the technology has gained attention especially for the static and dynamic charging of electric vehicles (EVs), where IPT offers possibilities that no other technology can match. In this work the influence on the coupler characteristics under certain parameter variation is analyzed and pointed out. By using state of the art finite element analysis (FEA) simulation the influence of different coupler parameters on the ground pad module (GPM) and car pad module (CPM) are evaluated. With the simulation results optimized mechanical coupler design can be achieved while keeping the mechanical specifications within given limits. By optimizing the coupler, the efficiency can be increased at different parking positions and ground clearances while limiting the electrical component stress. A fully functional prototype was built and verifies the behavior of the FEA simulation results. It demonstrates a DC to DC efficiency of up to 95%.

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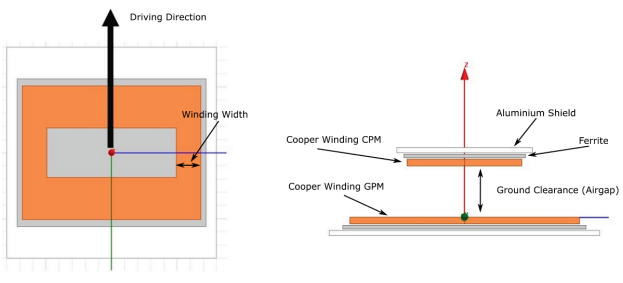
Motivation and System Overview

The central element of an IPT system is the magnetic coupler. The geometric parameters of the coupler have a strong impact on the behavior of the system. Several geometric parameters such as winding width, CPM size and ratio of GPM/CPM size have been investigated to study the effect on the inductance values and the coupling to derive an optimal geometry. Several design constraints limit the freedom of choosing the parameters.



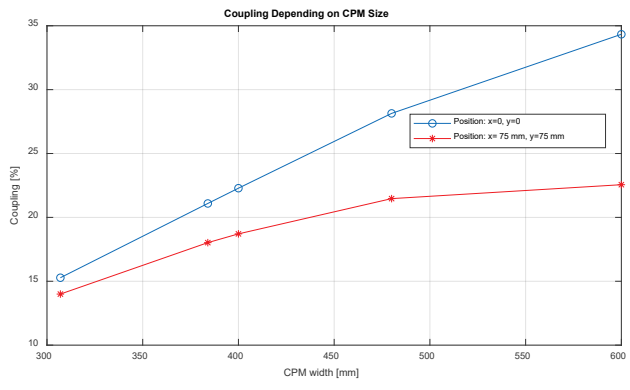
Specifications

The simulated coupler design is based on the key specifications shown in the table below. The charging system can be connected to a standard three phase 32 A outlet and allows charging an EV within a few hours. The values for the ground clearance and the frequency range meet the standards IEC 61980 and SAE J2954.

Nominal power	22000 W
Input voltage	600 – 800 V
Battery voltage	330 – 440 V
Nominal switching frequency	81.3 – 90 kHz
Transmitter dimensions	800 mm x 800 mm
Receiver dimensions	500 mm x 500 mm
Ground clearance	100 – 150 mm
Misalignment	±75 mm / ±100 mm

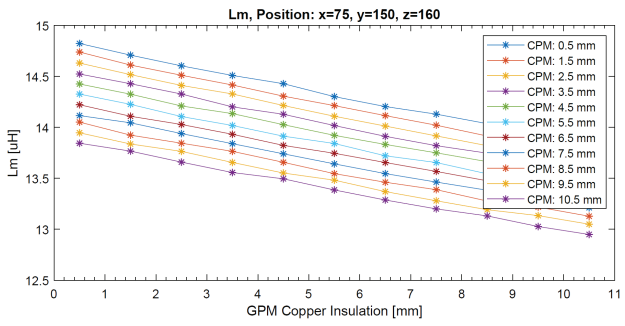
Size of Transmitter and Receiver

A critical factor is the size of the CPM. Under the assumption of a fixed size GPM and an air gap of 100mm, increasing the size of the CPM leads to a significantly increased coupling coefficient, as shown in the figure for two misalignment positions.
The coupling ratio kmax/kmin should be as low as possible. It can be shown, that the coupling ratio is linked to the ratio of the size of the GPM and the CPM.



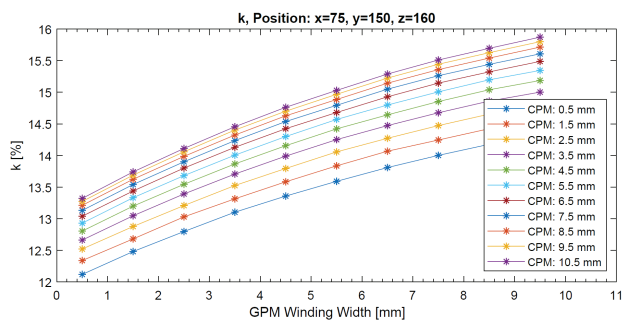
Cooper and Ferrite Distance

The distance between the winding and the ferrite (copper insulation) has a strong impact on the inductance values.
The figure shows the impact on the magnetizing inductance. If the copper insulation (insulation between the ferrite and the winding) at the GPM is enlarged from 1mm to 10mm the magnetizing inductance and coupling decreases by about 10%.



Winding Width Variation

Another parameter is the distance between the turns and therefore the total winding width. By varying this parameter on the GPM and CPM side, the coupling shows a strong dependence. By doubling the winding width of sender or receiver the coupling will increase independently by about 10% whereas the leakage inductance varies by almost 50%. The magnetizing inductance, however, remains unaffected.



Conclusion

The influence on the inductance values as well as the coupling coefficient of the coupler geometry is analyzed using state of the art finite element analysis (FEA) simulation.
Based on the mechanical requirements concerning coupler dimensions, misalignment, winding width and other parameters, FEA simulations have been carried out. Results of the simulations are the self inductance values (L1 and L2) as well as the mutual inductance M between the transmitter and the receiver. The main goal is to keep the coupling variation as small as possible while achieving a high coupling coefficient. By doing this, the coupler design can be optimized for high efficiency and low component stress while maintaining the mechanical specifications. Measurements on a hardware demonstrator verifies the simulation results.

References

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