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Influence of Physical Discontinuities on Eddy Current Effects in Homopolar Permanent-Magnet Arrays for Maglev Applications

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Objective

Hybrid electromagnetic suspension (HEMS) is a promising levitation architecture with reduced power consumption as permanent magnets (PMs) provide a passive force bias. It represents an enabler for commercial maglev system implementation. With levitation modules arranged in a transverse-flux (homopolar) configuration, less losses are provisioned with respect to a heteropolar configuration, interacting with a non-laminated rail. This is especially appealing for maintaining low infrastructure costs. Although levitation module continuity is preferable, it cannot be guaranteed in practice due to bogie auxiliary systems and train articulation requirements. Discontinuities are responsible for induced eddy currents at non-zero speeds, introducing parasitic lift and drag forces. Lift suppression and drag both worsen as speed increases. Loss in lift force results in increased levitation power consumption and drag force presents an additional load for the propulsion drive to sustain. The aim of the present work is to investigate the role of magnetic flux discontinuities on the severity of eddy current effects in homopolar PM arrays for maglev applications.

Method

Small-scale homopolar PM modules arranged in continuous and discontinuous configurations are modelled and tested on a magnetic levitation test bench. The system is modelled using the Fourier transform of the magnetic flux density, following the approach in literature. The model is refined considering the presence of PMs as well as physical phenomena such as magnetic flux leakage and skin depth. Moreover, static lift force computation necessary for the model is made using an equivalent magnetic circuit. Magnetic flux density distribution for continuous and discontinuous arrays is analytically computed, along with induced eddy current density. The relationship between eddy current vortex count and magnetic flux discontinuities is discussed. Forces are also computed and compared to those acquired experimentally. A range of air gaps (5 –7 mm) and speeds (1.5 –28 m/s) are investigated.

Results

Analytical and experimental results show good agreement, with average errors across speeds and air gaps below 0.4 N for all forces. Results show the importance of reducing discontinuities in the interest of maintaining low magnetic drag. Indeed, the horizontal Lorentz force component is dominant and shows a relative increase of 57% between continuous and discontinuous arrays, for maximum speed and minimum air gap conditions. Parasitic lift force suppression remains an issue as well; however, it is not significantly exacerbated by the introduction of magnetic flux discontinuities. In this context, a relative increase of 13% is observed for maximum speed and minimum air gap conditions.

Conclusions

Analytical and experimental analysis of homopolar PM arrays in continuous and discontinuous configurations highlights the need for the appropriate design of HEMS modules for maglev applications. An increase in magnetic drag presents larger loads for the propulsion drive to sustain, lowering overall system efficiency. Moreover, lift force suppression is also of concern for high-speed operation and additionally impacts system efficiency due to power consumption from compensatory magnetic flux strengthening using active coils. These parasitic forces can be mitigated by ensuring levitation module continuity where possible. The presented analytical model reproduces experimental force behaviour at different speeds and air gaps and can be used to estimate performance at the design stage.

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