Impact of Slot Dimensions on Performance of Linear Synchronous Motors with Large Air-Gaps

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Abstract

Introduction: Similar to a typical rotating electric motor, the two components of a linear machine are the primary windings and a secondary mover (reaction plate). As shown in Figure 1, in a permanent-magnet linear synchronous motor, the reaction plate consists of an array of strong rare-earth magnets whereas the stator comprises copper wire coils arranged within slots in a ferromagnetic core. Several stator sections are mounted end-to-end to form a long track.

The fundamental high-level motor design equation is: F = BQA where F is the force produced, B is the magnetic loading, Q is the specific electrical loading, and A is the air-gap surface area.

The air-gap size is ultimately constrained by mechanical considerations, so in order to produce more force, the magnetic loading and specific electrical loading need to be maximized. It is for this reason that the slot proportions are so important for motor design. The larger the slots are, the more cross-sectional area of conductor can be accommodated and so the specific electrical loading is higher for the same conductor current density. On the other hand, making the teeth larger allows more flux to flow before saturating which permits one to have larger magnets, and therefore, higher magnetic loading.

A parameterized COMSOL Multiphysics® model will be used to optimize the slot dimensions for an integral-slot narrow-phase-spread three-phase winding. Steady-state magnetic field parametric sweeps of key dimensions such as slot width, tooth width, air gap size will be run to find the optimum design (refer to Figure 2). Multi-turn coils will be used to simulate the stator windings and B-H curves will be used to specify behavior of the non-linear materials. Results for a high permeability linear core will determine the optimum points due purely to the geometry of the slots. These results will be compared to results obtained with a non-linear material where it becomes saturated at a high magnetic flux density, particularly in the stator teeth.

Results: The goal of this study is to find an optimum number of slots per pole per phase and slot width to tooth width ratio for the design of linear synchronous machines with large air-gaps. Plots of the different parametric sweep results will be shown to demonstrate the optimum points and trade-offs of the different designs. Flux wave analysis line graphs and harmonic analysis will be used to compare the quality of the waveforms produced along the air-gap. Two dimensional surface and contour plots will illustrate the flux distribution and paths.

Conclusion: The study and analysis of the trade-offs of the geometry of the stator teeth and slots are extremely important in motor design. There are good rules of thumb that have been traditionally used to determine the optimum proportions. Using COMSOL Multiphysics® to investigate, corroborate or simply optimize these rules of thumb is easier, more efficient, faster and more precise than using analytical methods.

Figures used in the abstract

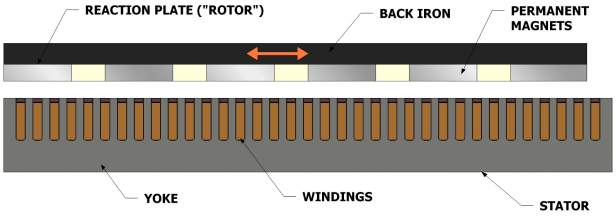

Figure 1

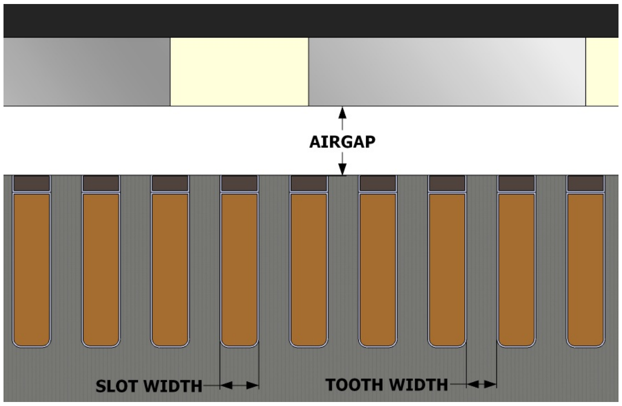

Figure 2