Comparison of control oriented models for the Long-Stator Linear Synchronous Motor and their experimental validation

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Organization

• Introduction
• Motor Description
• Motor Models
• Results
• Conclusions
Introduction

Linear Motors

• Replace rotative motors + rotative-to-linear transmissions
• Possibility of new applications
• Characteristics
  - higher dynamic response
  - no backslash
  - higher efficiency
  - still more expensive (motor + control)
• Known since a long time (e.g. Laithwaite 1971)
• It is only recently that instances of application are found
  Due to the advances in:
    - power electronics
    - signal processing and
    - control systems
Introduction

Linear Motors

• One key for designing a control system is to have an adequate model
  - Magnetic saturation
  - Non-sinusoidal flux
  - Non-periodic characteristics (end effects)
  - Cogging force

• Two approaches are analyzed for modeling a Linear Motor:
  - Based on Finite Element Analysis (FEA)
  - Based on Magnetic Equivalent Circuits (MEC)

• Model oriented for:
  - Simulation of the drive (more features than the fundamental wave model)
  - Design of the controllers
Motor Description

• Linear motor

• Permanent Magnet (PM) synchronous motor
  - high efficiency
  - high power density
  - allows a higher air gap

• Long stator (carriageway) - Short mover (vehicle)
  - passive mover: no brushes or cables connected
  - longer travel distance
Motor Description

- Pole pitch $\tau = 30$ mm
- Stator: 13 poles
  - 39 slots
- Mover: 3 poles
- Nominal Force 500 N
- Nominal Current 54 A
Motor Description

- One segment
- Load machine
- Path
- Mover

1 m
Motor Model

Interior permanent magnet motor (IPM)

Geometry

Magnetic characteristics

\[ 0 = f_2(\lambda, i, a, x) \]

\[ F_E = f(a, x) \]

Electrical

\[ \frac{d\lambda}{dt} = -RI + u \]

Stationary frame

\[ \frac{dv}{dt} = \frac{1}{M} (F_E - Bv - F_L) \]

Mechanical

\[ \frac{dx}{dt} = v \]
Motor Model: Magnetic Equivalent Circuit

\[ 0 = f_1(F_S, a_1, a_2, a_3, \phi_S, \phi_M(x)) \]
\[ \lambda = w^n \Phi_S \quad F_S = w^n i \]

Virtual Work

\[ F_E = (a_2 - a_3 \mathbf{1}_{40 \times 1})^T \frac{d\phi_M(x)}{dx} \]
Motor Model: Magnetic Equivalent Circuit

Flux facing the tooth, due to the magnet

\[ \phi_M(x) = B_r l_s b_G(x) \]
Motor Model: Finite Element Analysis

2D Magnetostatic Simulation
Results (Static)

MEC based model

Force vs. Position

Three Segments connected in series

Fed with $q$-current in the field oriented frame

FEA based model

Experimental test
Results (Dynamic)

Voltage step in the field oriented frame
\(v_q = 50V\)
Conclusions

- Slight differences between models and experimental tests
- High agreement between results of both models
- Future work: use of MEC based model for analysis of magnetic saliencies (for sensorless position detection).

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