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

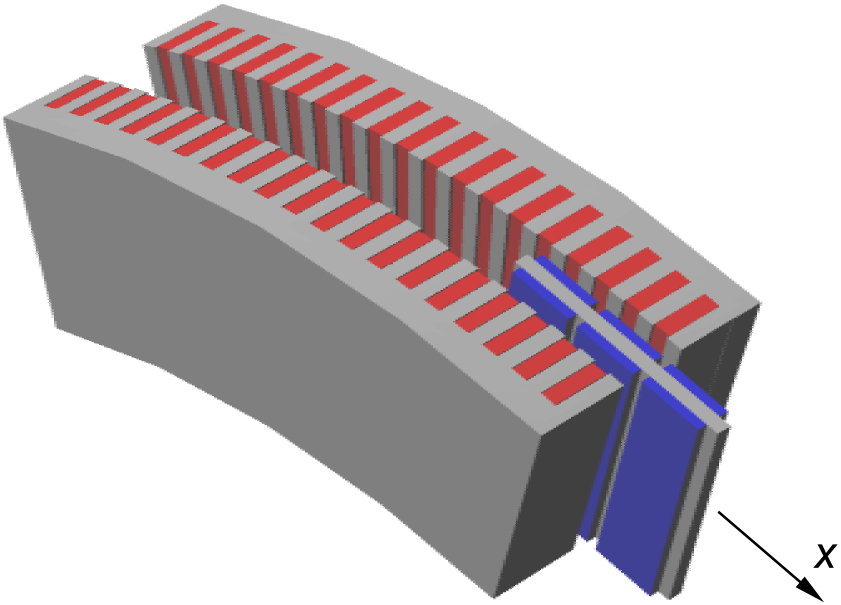
Motor Description

- Linear motor

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

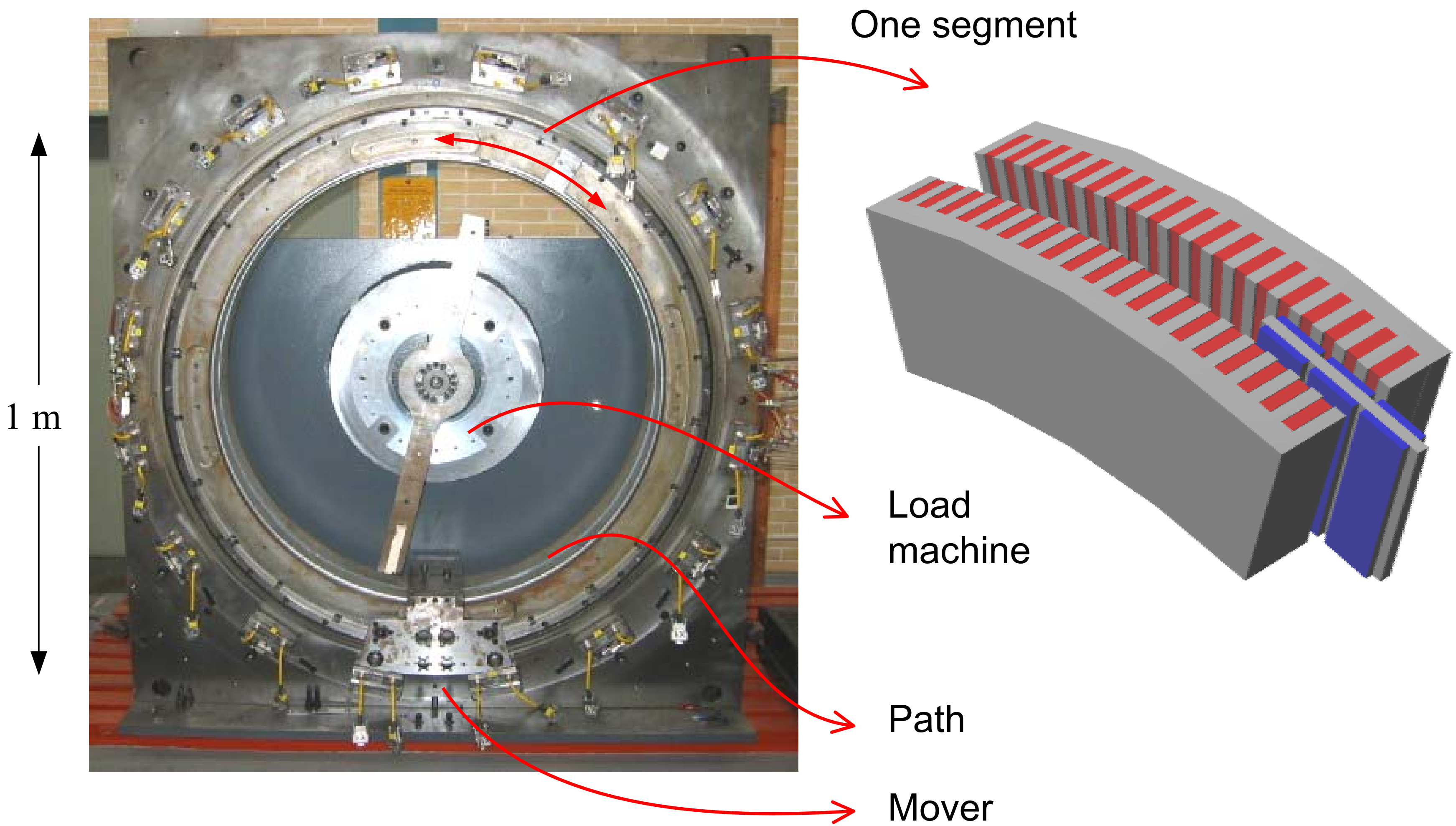
- Long stator (carriageway) - Short mover (vehicle)
  - passive mover: no brushes or cables connected
  - longer travel distance

Motor Description



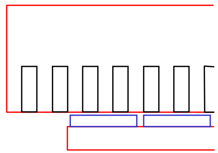
- Pole pitch τ = 30 mm
- Stator: 13 poles
  39 slots
- Mover: 3 poles
- Nominal Force 500 N
- Nominal Current 54 A

Motor Description

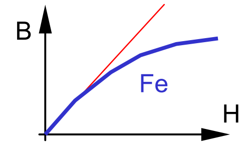


Motor Model

Geometry

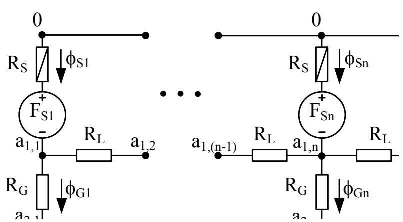


Magnetic characteristics



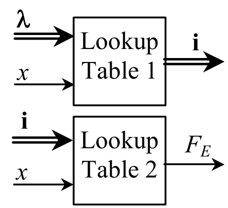
MEC

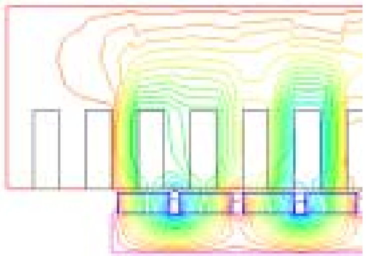
FEA



$$\mathbf{0} = \mathbf{f}_2\left(\boldsymbol{\lambda}, \mathbf{i}, \mathbf{a}, x\right)$$

$$F_E = f\left(\mathbf{a}, x\right)$$





Electrical

$$\frac{d\boldsymbol{\lambda}}{dt} = -R\,\mathbf{i} + \mathbf{u}$$

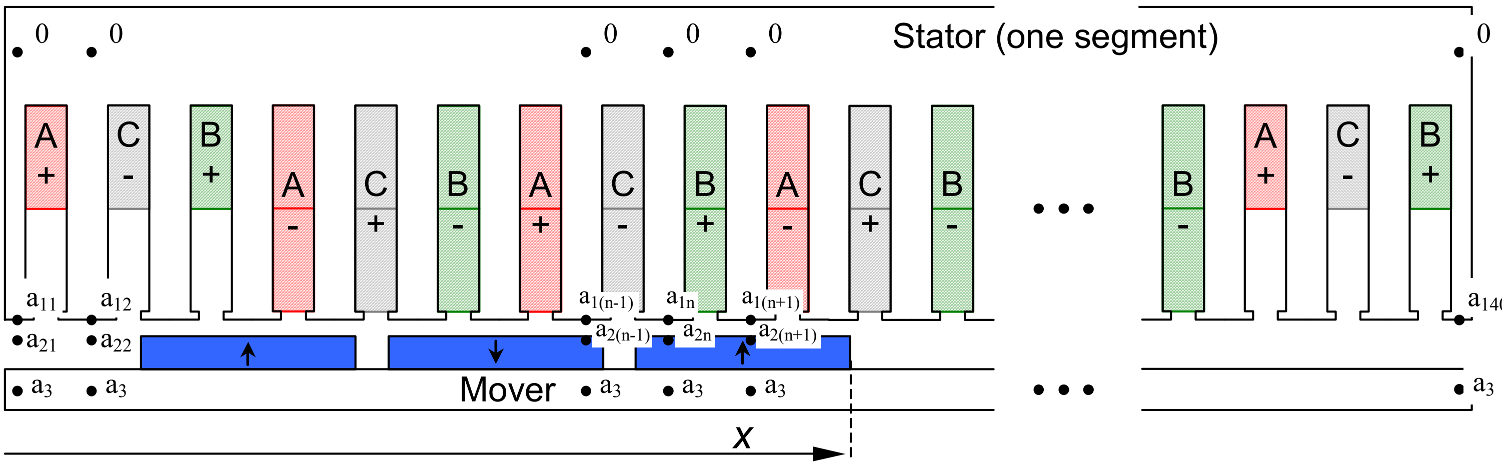
Stationary frame

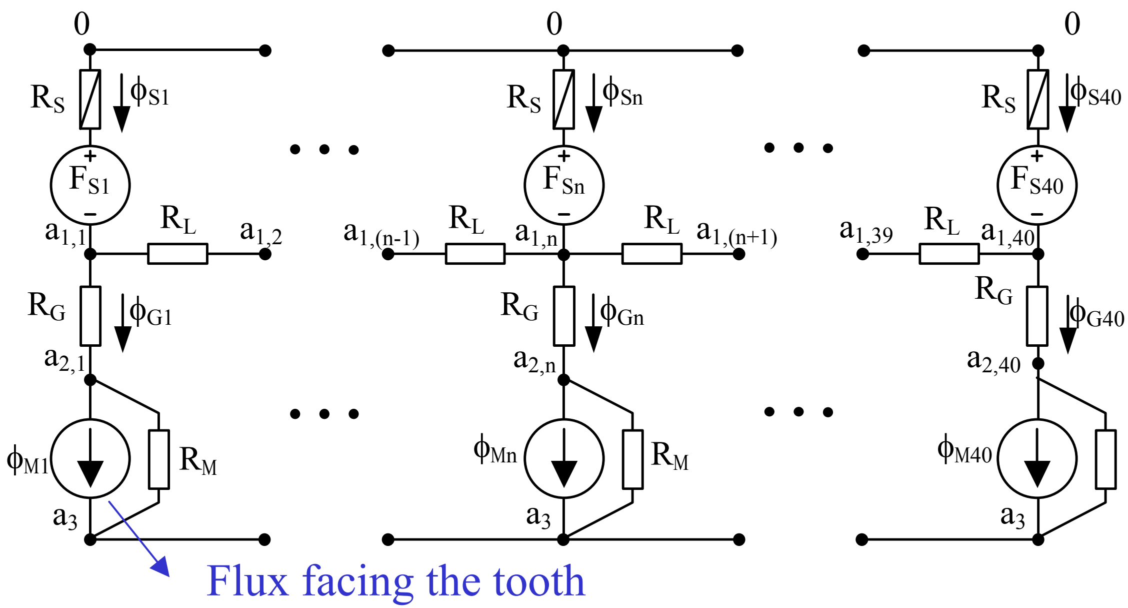
Mechanical

$$\frac{dv}{dt} = \frac{1}{M}\left(F_E - B\,v - F_L\right)$$

$$\frac{dx}{dt} = v$$

Motor Model: Magnetic Equivalent Circuit





$$0 = \mathbf{f}_1\left(\mathbf{F}_S, \mathbf{a}_1, \mathbf{a}_2, a_3, \boldsymbol{\varphi}_S, \boldsymbol{\varphi}_M(x)\right)$$

$$\boldsymbol{\lambda} = \mathbf{w}''^T \boldsymbol{\varphi}_S \qquad \mathbf{F}_S = \mathbf{w}'' \, \mathbf{i}$$

$$0 = \mathbf{f}_2\left(\mathbf{i}, \mathbf{a}_1, \mathbf{a}_2, a_3, \boldsymbol{\lambda}, \boldsymbol{\varphi}_M(x)\right)$$

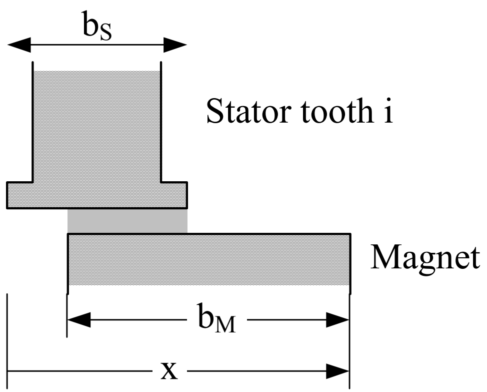
Virtual Work

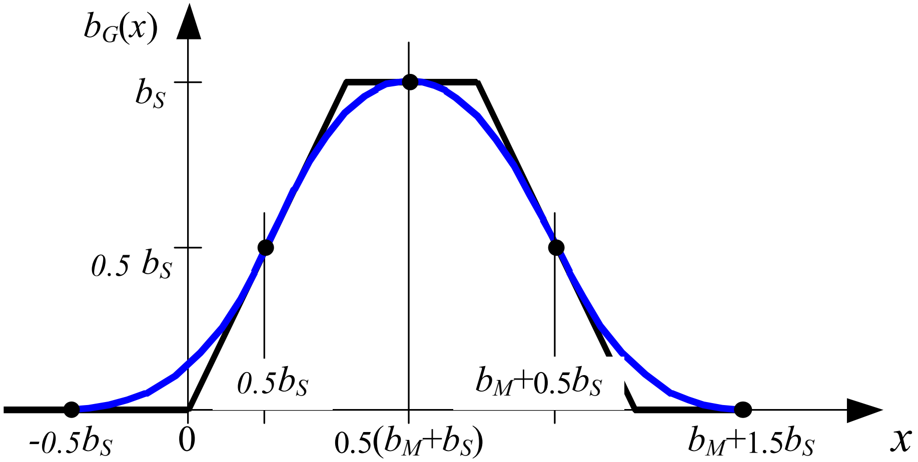
$$F_E = \left(\mathbf{a}_2 - a_3 \mathbf{1}_{40x1}\right)^T \frac{d\boldsymbol{\varphi}_M(x)}{dx}$$

Motor Model: Magnetic Equivalent Circuit

Flux facing the tooth, due to the magnet

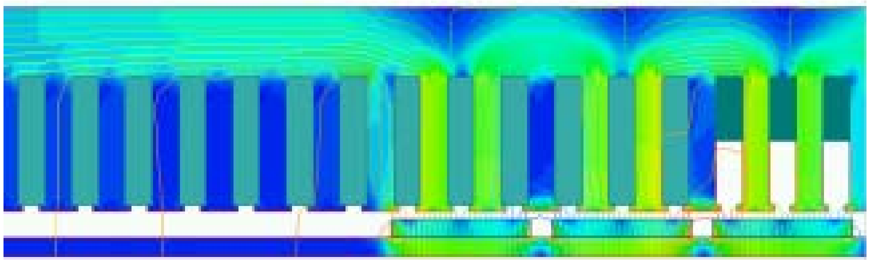
$$\phi_M(x) = B_r\, l_S\, b_G(x)$$

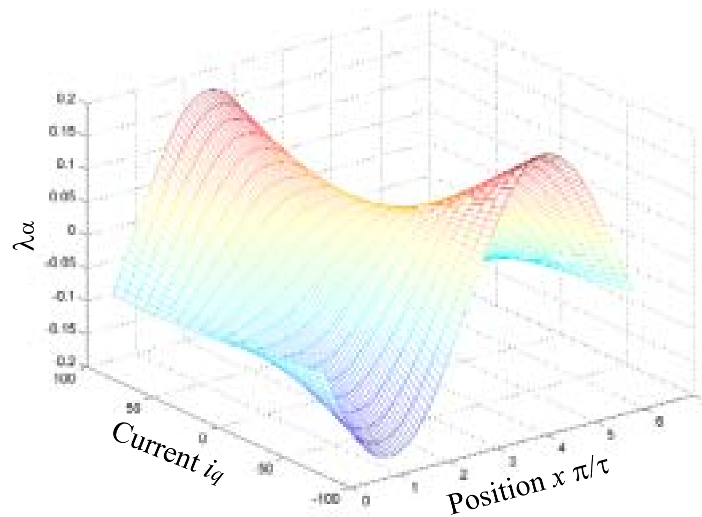


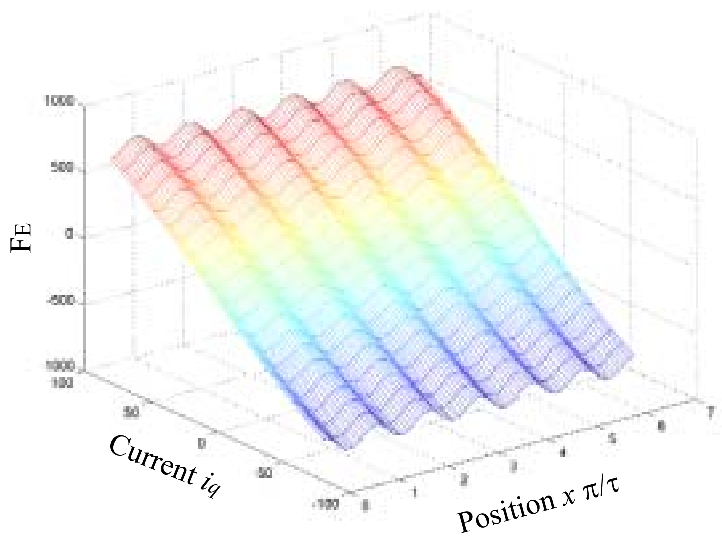


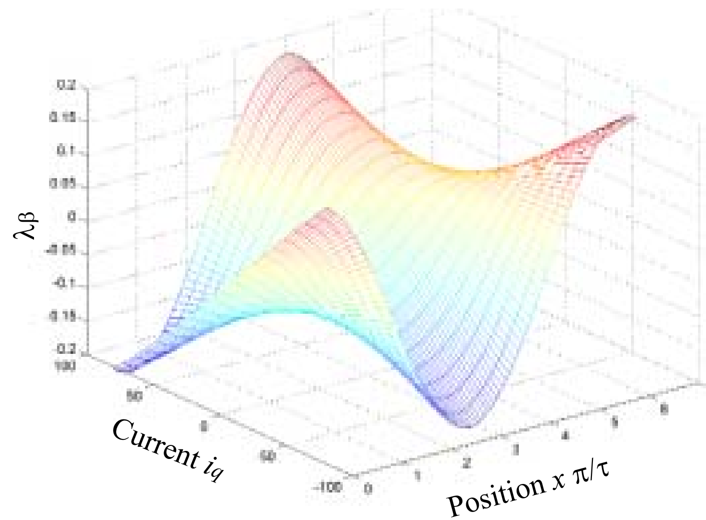
Motor Model: Finite Element Analysis

2D Magnetostatic Simulation



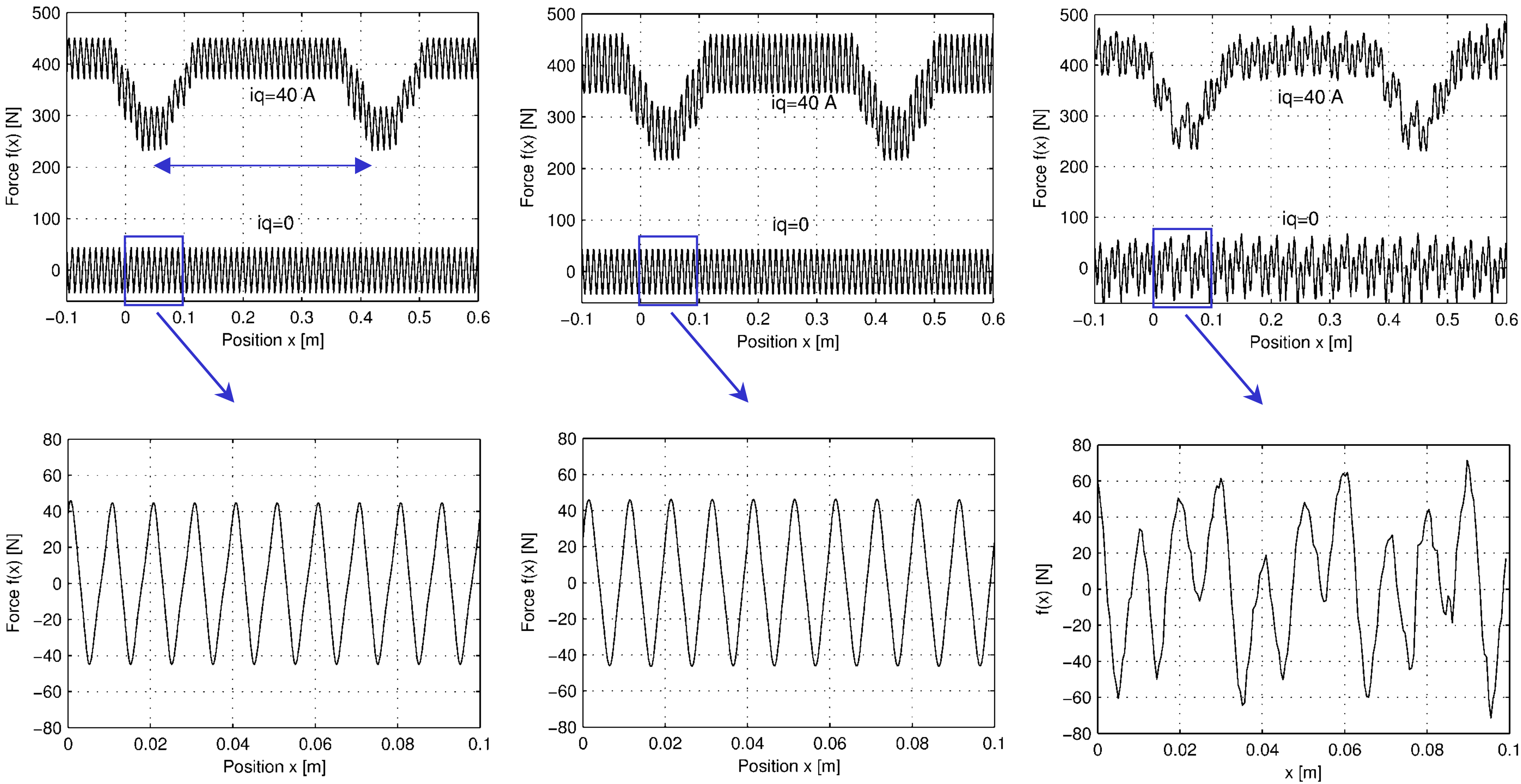






Results (Static)

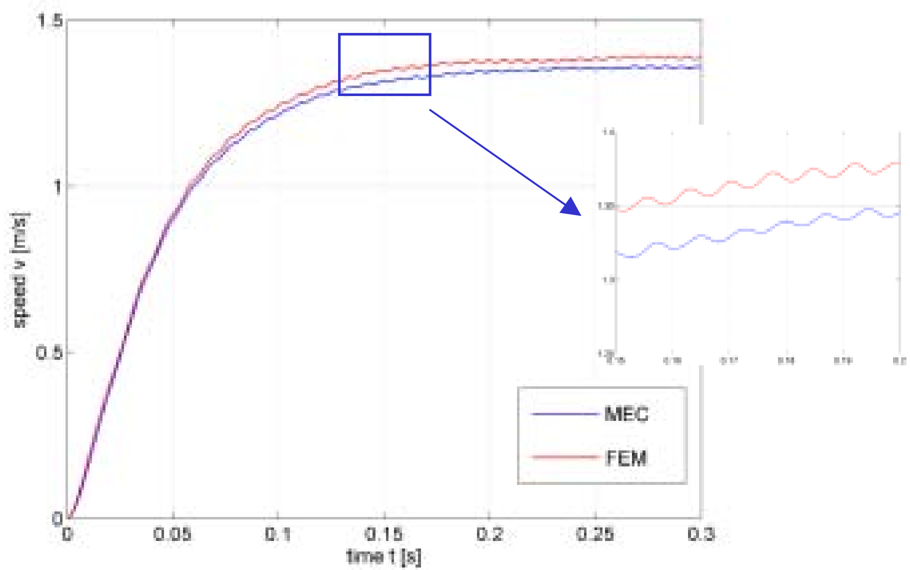
MEC based model | FEA based model | Experimental test



Results (Dynamic)

Voltage step in the field oriented frame

$v_q = 50\text{V}$



Conclusions

	FEA based model	**MEC based model**
Model preparation	Simple and Systematic	Requires special skills More decisions must be taken by the developer
Offline computations	Slow (days)	Fast (minutes)
Simulations	Very fast (minutes)	Very fast (minutes)

- 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).

Alexander von Humboldt
Stiftung / Foundation

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▸ http://www.humboldt-foundation.de