

# On PM Tubular Linear Synchronous Motor Modelling

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**Abstract:** In this paper a new approach is made on PM tubular linear synchronous motor (PM-TLSM) modelling, considering a non linear model. This model allows the incorporation of PM elements characteristics. The straight forward approach induces robust simulation results for tubular linear machines, without resorting to complex variable transformations.

**Key-Words:** Linear machines, Tubular motor, Permanent-magnets, Modelling and Simulation.

## 1 Introduction

A linear motor applies force directly to a load, and does not require any intermediate mechanism to convert rotary motion into linear motion. Linear motors are capable of high speeds, fast acceleration, and accurate positioning.

The linear motors are employed in a wide range of electromechanical systems, such as robotics and factory automation, processing and packaging equipment, machine tools, transfer equipment, aerospace industry and transportation systems. An industrial applications issue of the linear actuators is present in [1].

When providing motion for people-moving devices or virtual reality capsules, it's important to provide a clean environment. The linear motors can offer significant advantages over conventional linear motion systems, such as hydraulic linear actuators, motors drives by cams, ball screws and belts, in terms of efficiency, low cost maintenance, no power loss in rotary-linear conversion, speed and force control and positional accuracy [2].

The linear synchronous machines (LSM) are selected for some applications, because they have significantly higher force production then linear induction and switched reluctance motors. This preference is justified by the improvements of permanent magnet materials and power electronics devices [3].

There are several topologies of LSM, these topologies vary with some parameters i.e. excitation mode, type and permanent magnets placement, slotted or slotless armature design.

A permanent magnet tubular linear synchronous motor (PM-TLSM) topology is considered in this paper. The different PM-TLSM topologies and their comparative studies are present in [4]-[6].

## 2 PM Tubular Linear Synchronous Motor

### 2.1 Development of linear motor geometries

To understand the linear machines modelling based on rotary machines knowledge, geometrically it can be "cut" along radial plane and "unrolled". This is exemplified in Figure 1(a) and Figure 1(b). Applying this process to a PM rotary synchronous motor a PM flat LSM is obtained. The PM-TLSM can be developed from flat linear motors by "rolling" them around their longitudinal axis. The permanent magnets, initially oriented along the length of the linear shaft, now form a stack of alternating magnetic polarity rings, Figure 1(c).

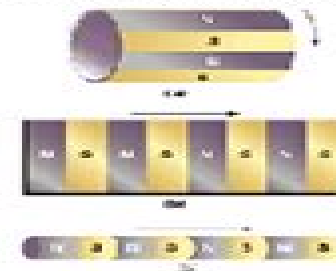


Fig.1: (a) Rotary motor; (b) Flat linear motor; (c) Tubular linear motor.

# On Pm Tubular Linear Synchronous Motor Modelling

**Ion Boldea**



## **On Pm Tubular Linear Synchronous Motor Modelling:**

*Linear Synchronous Machines* Amal Souissi, Imen Abdennadher, Ahmed Masmoudi, 2018-11-17 This book introduces readers to two major sustainable applications of linear synchronous machines wave energy conversion and magnetic levitation train technology To do so it begins with a state of the art review of linear machines covering induction and synchronous topologies and their applications with a particular focus on sustainable applications This is followed by an analysis of the electromagnetic modeling of linear synchronous machines the goal being to investigate their main features especially their force production capabilities *Linear Electric Machines, Drives, and MAGLEVs Handbook* Ion Boldea, 2023-07-31 Linear motion is richly present in various industries from direct electric propulsion in urban and interurban people movers on wheels or on magnetic cushions MAGLEVs to indoor transport of goods conveyors etc through plunger solenoids to open hotel doors and as electromagnetic power switches to compressor drives by linear oscillatory permanent magnet PM motors smart phones integrated microphone and loudspeakers and controlled vehicles suspension etc Besides the traditional rotary motor drives with mechanical transmissions which mean friction limitations weather dependent in traction heavy vehicles more losses positioning errors backlash in the process and higher maintenance costs to handle them linear motion in industry by direct electromagnetic forces is free of friction limitations for traction free of mechanical transmission and thus more efficient with less maintenance cost and fewer positioning errors backlash This explains why they are used in so many applications already since the dramatic advancement of power electronics and digital control in the last four decades Modeling performance design control and testing of linear electric machines LEMs show notable differences with respect to rotary electric motor drives which warrant a dedicated treatment of these aspects The Second Edition First Edition 2013 concentrates on the above technical aspects of various types of LEMs in close relationship with specific applications via numerical examples of modeling design control and testing with ample representative results from literature industry and some of the author s contributions such as Technical field and circuit modeling of linear induction motors in flat configurations for low and high speeds with and without dynamic end effects and in tubular configurations short travel design control and testing Linear synchronous motor LSM drives in dc excited homopolar reluctance and superconducting excitation configurations for urban and interurban high speed vehicles propulsion and integrated propulsion and levitation in MAGLEVs modeling design and control with full scale numerical examples with emphasis on lower kWh passenger Km at high speeds Flat and tubular linear permanent magnet PM synchronous motors L PMSMs mainly destined to industrial indoor transport for automation at high efficiency in clean rooms Linear flux modulation motors new breed suitable for very low speed applications due to higher thrust density Plunger solenoids in various applications including new valve PM actuators with millisecond response time Linear resonant PM oscillatory motors design control and testing mainly destined to compressors for higher efficiency in compact drives Attraction and repulsive force suspension levitation systems

for MAGLEVs Active and passive guideway MAGLEVs in urban and superhigh speed interurban transport at lower Kwh per passenger km in lighter vehicles without wheels The numerous numerical design and control examples with practical specifications throughout the 23 chapters of the book allow the reader deep and fast access to a practical but thorough unitary good for comparisons methodology in designing and controlling LEMs for various applications

*Renewable Energy in the Service of Mankind Vol I* Ali Sayigh, 2015-09-09 This book provides insights on a broad spectrum of renewable and sustainable energy technologies from the world's leading experts It highlights the latest achievements in policy research and applications keeping readers up to date on progress in this rapidly advancing field Detailed studies of technological breakthroughs and optimizations are contextualized with in depth examinations of experimental and industrial installations connecting lab innovations to success in the field The volume contains selected papers presented at technical and plenary sessions at the World Renewable Energy Congress the world's premier conference on renewable energy and sustainable development Held every two years the Congress provides an international forum that attracts hundreds of delegates from more than 60 countries

**Third Harmonic Utilization in Permanent Magnet Machines** Kai Wang, Zi-Qiang Zhu, 2018-08-29 This book investigates the utilization of harmonics in the permanent magnet PM or rotor shape to improve the torque density of PM brushless AC machines including three phase inner rotor and outer rotor machines five phase machines dual three phase machines linear machines by means of analytical finite element analyses and as well as experimental validation The torque density can be improved while the torque ripple remains low in PM shaping utilizing the 3rd harmonic In this book the analytical expression of output torque is derived for PM machines with rotor shape using the 3rd harmonic and then the optimal 3rd harmonic for maximizing torque is analytically obtained The book compares the PM shape in surface mounted PM SPM machines and the rotor lamination shape in interior PM IPM machines utilizing the 3rd harmonic and it becomes clear that their shaping methods and amount of torque improvement are different In a five phase PM machine the 3rd harmonic can be utilized in both the current waveform and PM shapes to further improve the output torque For the dual three phase SPM machines without deteriorating the torque more than 30% when the optimal 3rd harmonic into both the current and PM shape are injected The harmonics in airgap flux density have significant influence on the cogging torque stator iron flux distribution and radial force between the rotor and stator These effects has been investigated as well in this book

**Science Abstracts**, 1995 Multidisciplinary Design Optimization Methods for Electrical Machines and Drive Systems Gang Lei, Jianguo Zhu, Youguang Guo, 2016-02-05 This book presents various computationally efficient component and system level design optimization methods for advanced electrical machines and drive systems Readers will discover novel design optimization concepts developed by the authors and other researchers in the last decade including application oriented multi disciplinary multi objective multi level deterministic and robust design optimization methods A multi disciplinary analysis includes various aspects of materials electromagnetics thermotics

mechanics power electronics applied mathematics manufacturing technology and quality control and management This book will benefit both researchers and engineers in the field of motor and drive design and manufacturing thus enabling the effective development of the high quality production of innovative high performance drive systems for challenging applications such as green energy systems and electric vehicles **Handbook of Research on Green Engineering**

**Techniques for Modern Manufacturing** Uthayakumar, M., Raj, S. Aravind, Ko, Tae Jo, Kumaran, S. Thirumalai, Davim, J. Paulo, 2018-11-16 Green manufacturing has developed into an essential aspect of contemporary manufacturing practices calling for environmentally friendly and sustainable techniques Implementing successful green manufacturing processes not only improves business efficiency and competitiveness but also reduces harmful production in the environment The Handbook of Research on Green Engineering Techniques for Modern Manufacturing provides emerging perspectives on the theoretical and practical aspects of green industrial concepts such as green supply chain management and reverse logistics for the sustainable utilization of resources and applications within manufacturing and engineering Featuring coverage on a broad range of topics such as additive manufacturing integrated manufacturing systems and machine materials this publication is ideally designed for engineers environmental professionals researchers academicians managers policymakers and graduate level students seeking current research on recent and sustainable practices in manufacturing processes

**Energy Efficiency in Electric Devices, Machines and Drives** Gorazd Štumberger, Boštjan Polajžer, 2020-06-18 This Special Issue deals with improvements in the energy efficiency of electric devices machines and drives which are achieved through improvements in the design modelling control and operation of the system Properly sized and placed coils of a welding transformer can reduce the required iron core size and improve the efficiency of the welding system operation New structures of the single phase field excited flux switching machine improve its performance in terms of torque while having higher back EMF and unbalanced electromagnetic forces A properly designed rotor notch reduces the torque ripple and cogging torque of interior permanent magnet motors for the drive platform of electric vehicles resulting in lower vibrations and noise In the field of modelling the torque estimation of a Halbach array surface permanent magnet motor with a non overlapping winding layout was improved by introducing an analytical two dimensional subdomain model A general method for determining the magnetically nonlinear two axis dynamic models of rotary and linear synchronous reluctance machines and synchronous permanent magnet machines is introduced that considers the effects of slotting mutual interaction between the slots and permanent magnets saturation cross saturation and end effects Advanced modern control solutions such as neural network based model reference adaptive control fuzzy control senseless control torque speed tracking control derived from the 3D non holonomic integrator including drift terms maximum torque per ampere and maximum efficiency characteristics are applied to improve drive performance and overall system operation [Index to Theses with Abstracts](#)  
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,2006     Second International Conference on Power Electronics, Machines, and Drives (PEMD 2004) ,2004     *Proceedings of the Eleventh International Symposium on Applied Electromagnetics and Mechanics, ISEM-Versailles A.*

Bossavit,Dominique Lesselier,A. Razek,2004 This publication contains a selection of 124 papers among the 165 full length contributions which were submitted on site at ISEM 2003 The objective of the symposia series is to vigorously promote the research in the field of electro mechanical systems The reader will we hope appreciate the variety of topics that were addressed This is what makes ISEM so stimulating for whoever is interested in the applications of electromagnetics and its opening toward many technical fields Yet this publication does not intend to be a mosaic of sub disciplines but aims at their integration and synergy This will be demonstrated by the present selection     **Proceedings** ,1999     IMACS '91 Robert Vichnevetsky,John James Henry Miller,1991     IMACS '91, 13th World Congress on Computation and Applied Mathematics

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