I. INTRODUCTION

It has been a pleasure to assemble these outstanding papers on Linear Motor Powered Transportation: Past, Present, and Future. This topic takes on increasing importance as we seek ways to make transport systems faster, more efficient, and more affordable. We were able to recruit outstanding engineers and managers to devote many hours to writing these papers, which come from six countries on three continents. The authors are from industry and academia, and are all experts in their field. We encouraged the authors to describe current supporting technology and linear motor systems, past history, and projections for the future. These papers have broad coverage of important ideas and can be understood by people who are not experts in the field. Many of the papers include substantial bibliographies that can be used to further explore the topics.

There are many types of linear motors, but most of those discussed in these papers are the short primary linear induction motor (LIM) and the long primary linear synchronous motor (LSM). They are similar to their rotary counterparts, but the linear versions represent a more complex design challenge. Some papers use the term stator for the part of the motor that is excited, but since this is sometimes on the moving vehicle, it seems better to use the transformer terminology “primary.” There is one paper on the long primary LIM. It is possible to build a short primary LSM, but there is no paper on this topic. Unless otherwise stated, LIM refers to transport systems in which power is transmitted to the vehicle and the guideway is passive, while LSM refers to systems in which the propulsion power is supplied to windings on the guideway and no propulsion power is transmitted to the vehicle.

One important application of linear motors is the propulsion of vehicles that are suspended by magnetic fields. In 1968, Coffey coined the term “maglev” to refer to a “transport system using magnetic suspension and propulsion.” There are two common types of maglev: electromagnetic suspension (EMS), in which the vehicle is supported by attractive forces between magnets on the vehicle and a ferromagnetic structure on the guideway, and electrodynamic suspension (EDS), in which magnets on the vehicle move in the vicinity of conducting material and currents induced in the conductors react with the vehicle fields to provide lift. A key part of maglev design is integration of a linear motor propulsion system with the suspension. Either LIM or LSM propulsion can be used with EMS and

This Special Issue on Linear-Motor Powered Transportation covers both supporting technologies and innovative transport systems in various parts of the World, as this technology moves from the lab to commercial operations.
Scanning the Issue

EDS, but in practice, LIM has only been used for EMS.

This issue is divided into two parts: supporting technology and transport systems. In the following two sections, we attempt to give a short synopsis of each paper.

II. SUPPORTING TECHNOLOGY

There are seven papers describing technology that is important to linear motor developers.

1) Permanent magnets: NdFeB permanent magnets are now used extensively for both rotary and linear synchronous motors, including motor designs described in this issue. Thompson has had considerable experience in designing these magnets into linear motor and magnetic brake applications. His paper clarifies important issues in the application of permanent magnets.

2) LIM control: Control of linear motors is similar to control of rotary motors, but there are important differences. Meeker and Newman’s paper is based on their work in developing a control system for an LIM launch system for U.S. Navy aircraft carriers. The resulting linear motor has the highest acceleration rate and peak power demand of any linear motor in operation today.

3) LSM control and block structure: Linear synchronous motors for transport must be broken into segments, or blocks, each with its own position sensing and control. Perreault has had extensive experience in developing LSM control systems, and his paper provides valuable insights into the design of the block structure and control algorithms.

4) Multilevel converters: Inverters and four quadrant rectifiers are now being used to provide excitation of linear motors. At high power levels, the most cost-effective solution is to use several lower power modules with outputs combined to produce higher power than is possible with commercially available lower power modules. The authors of this paper have created an excellent introduction to a topic that is important in high-power linear motor applications.

5) Modeling and simulation: Tools for modeling and simulation have improved dramatically over the approximately 40-year history of major linear motor development. It is doubtful if modern designs would be as effective as they are without these tools. Dudgeon et al. provide an example of simulation with some comments on future possibilities in the era of multiprocessing.

6) High-temperature superconductors: Superconductors have been used in several maglev designs, and the improved performance of the latest high-temperature superconductors could lead to substantial improvement in high speed transport systems. Hazelton and Selvamanickam describe some of the latest ideas in this evolving field.

7) Ultracapacitor: This relatively new type of capacitor can store exceptionally large amounts of energy and deliver very high peak powers. Ultracapacitors are used in electric vehicles and have promise for linear motor drives. The authors of this paper have developed some promising new ideas for increasing the performance of these capacitors.

Supporting technologies are described in many other IEEE publications. The April 2007 Special Issue on Electric, Hybrid Vehicles is particularly recommended. It includes papers on electrical machine drives, power converters, semiconductor power devices, batteries, and ultracapacitors.

III. LINEAR MOTOR SYSTEMS

There are eight papers that describe existing linear motor powered transport systems that are either operational or in a development phase.

1) Pipeline: Montgomery et al. describe a unique way to move coal with hopper cars in a pipe using linear motor propulsion. The linear motor allows rapid movement of large amounts of material with the potential to climb steep grades, and be efficient, and cost-competitive compared with conventional ways of performing this task.

2) Personal rapid transit (PRT): A PRT system is now being installed at Heathrow Airport, and several companies are developing other versions. Most PRT designs use rotary motor propulsion, but Vectus uses a long stator LIM. Gustafsson describes the design and operation of this unique linear motor.

3) Urban maglev: General Atomics (GA) has worked for several years to develop a maglev system optimized for use in urban areas at speeds up to 161 km/h (100 mph). Their design uses permanent magnets for an eddydynamic suspension with LIM propulsion. Gurol describes the GA design with thoughts on future applications of the technology.

4) Maglev in China: China has installed a high-speed Transrapid maglev system between Shanghai and Pudong Airport. This is the only operational high-speed maglev
system, and China has active plans for other installations. Yan describes maglev and linear motor developments in China, including a discussion of future opportunities for these technologies in China.

5) **Superconducting maglev:** Japan has worked for many years to develop a superspeed maglev system using superconducting magnet EDS with LSM propulsion. The design has been tested at speeds up to 581 km/h, and commercial operation at a maximum speed of 550 km/h is planned to start in 2025. Sawada describes this design and future development plans.

6) **Korea urban maglev:** Korea has constructed an urban maglev test facility and is actively working on a project to install this system between Seoul, South Korea, and Incheon airport. This design uses EMS suspension and LIM propulsion with a maximum operating speed of 110 km/h. Park et al. describe this system and plans for installation by 2012.

7) **Linear motor overview:** A 30 km installation of the German Transrapid system is now operational in Shanghai, China. This system, referred to in (4), is the only commercially operating high-speed maglev design, but there are active plans for other installations. Hellinger and Mnich have been involved in this development, and in this paper, they provide an overview of types of linear motors and their applications with specific reference to maglev systems.

8) **Urban maglev:** MagneMotion is the second U.S. company that is supported in part by the Federal Transit Administration to develop an urban maglev system. In this paper, Thornton describes the MagneMotion M3 maglev system and opportunities for efficient and affordable maglev in the United States. There are other operating and development linear motor transport systems that are described on the Internet. Particularly noteworthy is the Bombardier Advanced Transit System that uses LIM propulsion with a steel wheel on steel rail suspension. Their design has demonstrated the advantages of linear motor propulsion in many applications throughout the world.

### IV. CONCLUDING THOUGHTS

There are many other papers that would be appropriate to this Special Issue, and omission of these papers does not in any way reflect on the importance of other technologies or system designs. The important conclusion is that linear motor power transportation is finally moving from the laboratory to commercial operation, and we can expect greatly increased interest by the IEEE community.

All of the topics discussed in this issue can be studied in substantial depth on various Internet sites. Searching terms like linear motor, maglev, and innovative transportation will lead you to these sites. We encourage readers with good ideas on these topics to submit papers to the IEEE for publication.
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