Magnetic Levitation

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Maglev Technology and Applications

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Foreword

In 2004 and 2005, high- and low-speed magnetic trains developed based on levitation technology was commercialized for a public transportation in China and Japan, respectively. For the last decade, they demonstrated their outstanding performance in various aspects of environmental friendliness, reliability, safety, and low operation and maintenance cost. Owing to this success, magnetically levitated trains will become a promising transportation option in the future, in combination with conventional wheel-on-rail systems. Moreover, the applications of magnetic levitation will be increasing to high-speed transfer systems such as super elevators. Therefore, this is the opportune moment to have this definitive and comprehensive work on the topic.

The medium for levitation is the magnetic fields produced by permanent and superconducting magnets and electromagnets in a static or dynamic mode. The interaction between the magnetic fields produces either repulsive or attractive forces, which permit the levitation and propulsion of the objects without physical contact. A higher lift force/magnet weight ratio is desirable for efficient energy consumption. In addition, sufficient damping is required to guarantee smoother operation. Despite the advantage of requiring no energy, the application of permanent magnets in levitation has been rather limited because of their low lift force/magnet weight ratio and damping. Owing to the discovery of new magnetic materials and the invention of the Halbach array enabling an increased lift force/magnet weight ratio, however, permanent magnets are attracting more attention today. It is believed that the Halbach array, in particular, has much more potential. Superconducting magnets with a very high-strength magnetic field, i.e., higher lift force/magnet weight ratio, have been under development for many years. It resulted in the construction of a high-speed railway system L0, which will be in service in near future. Although this magnet requires the cryostat to maintain its superconductivity with low damping, it might be more attractive when high-temperature superconductors are discovered. The most widely used electromagnets inevitably need sophisticated feedback control systems to maintain constant separation between the objects. Once stable levitation control is available, it might be more attractive due to its capacity to adjust its motion with high precision and damping. In conclusion, the recent advances in power electronics and sensing technologies open up new applications of electromagnetic levitation that can provide lightweight systems and high-precision motion control.

The development of magnetic materials and electronic devices could offer more opportunities for us than ever before, including new magnetically levitated applications in railway, automation, aerospace, and entertainment. In particular, personal rapid transit could be realized by employing a suitable levitation technology for a particular application. Levitation technology, once a staple of science fiction movies and novels, will become a disruptive technology in the near future.

Yong-Taek Im
President of Korea Institute of Machinery and Materials

Preface

Magnetic levitation (suspension) for contactless operation has been in development as an alternative to wheel-on-rail systems since Graeminger first patented an electromagnetic suspension device in 1912. This led to a number of operational and experimental magnetic trains being constructed, for both low- and high-speed operations, which are currently in service or will be in several years. The well-known Transrapid, which runs at a maximum operating speed of 430 km/h, has been successfully operating without any operational problems since it was unveiled in 2004 in Shanghai, China, showing that electromagnetic suspension technology has in fact matured beyond expectations. The low-speed system using electromagnets, Linimo, also has been carrying 20,000 passengers per day in Nagoya, Japan, and has proven its advantages by offering a high level of reliability, considerable environmental appeal and lower maintenance costs. The Incheon International Airport Urban Maglev Demonstration Line in Korea and the Beijing and Changsa urban lines under construction in China will be opened in one or two years. On April 22, 2015, the Japanese superconducting magnet train L0 attained a running speed of 603 km/h, a record for any guided vehicle, and there are plans to operate this train over a route between Tokyo and Nagoya by 2027. These applications of magnetically levitated vehicles may prove that wheel-less transport could be a promising option as a new transportation mode in the future. On the other hand, as both the speed and the ride comfort performance of conventional wheel-on-rail vehicles have been considerably improved in recent years, the specific niche for magnetic vehicles in terms of speed as well as ride comfort is narrowing. It may be that magnetic vehicles are approaching a critical point that will determine their future viability. On the other hand, magnetic levitation technology is attracting strong interest for diverse applications in which the contact-free aspect is essential—examples include an extremely clean transfer system for LCDs and semiconductors, a rope-less elevator for skyscrapers and a hover board for entertainment purposes, and prototypes for these technologies have been demonstrated. With the rapidly increasing interest in its various forms and applications, there is an opportunity for engineers to play a dominant role in the development of contact-less or wheel-less operation systems.

The objective of this monograph is to discuss the principles of magnetic levitation and its operation in a way that can be understood by readers from various backgrounds. The authors also hope to promote a discussion that can lead to an enhancement of the current magnetic levitation system's competitiveness compared to conventional systems through innovation.

For ease of understanding and application, the three kinds of magnets, i.e., permanent, superconducting magnets, and electromagnet, in wide use are presented in a definitive and comprehensive manner with example cases and descriptions of the corresponding levitation concepts and configurations. The unique properties, advantages, and limitations, as well as significant problems of each magnetic levitation scheme, are discussed. In particular, railway applications are introduced chronologically and in more detail. The reader will find the book useful in imagining their own new concepts and identifying the basic design parameters. The majority of the content in this book can be understood by a reader who has studied university-level physics only, regardless of his or her major.

Much of this work, which has been supported by the MSIP, MOLIT, and KAIA, as well as the NST, was carried out in collaboration with the author's colleagues both at the KIMM (Korea Institute of Machinery and Materials) and from academic, research, and industry organizations.

Firstly, the authors would like to thank P.K. Sinha, the author of "Electromagnetic Suspension Dynamics & Control (1987)" for introducing them to the concept of magnetic levitation and providing the basis of this monograph by writing the first comprehensive and pioneering book in this area.

The authors would like to thank these colleagues for their contributions to the operational and experimental systems cited here. The contributions of Dr. Chang-Hyun Kim, Dr. Jae-Won Yim and Dr. Chang-Wan Ha and Dr. Han-Wook Cho to the magnetic system design, simulation, and test works given here are particularly acknowledged.

Technical details and figures quoted in the book are based on information available in the public domain, including via the Internet. In particular, the authors thank Dr. Byung-Chun Shin, a director of Center for Urban Maglev Program, for supplying information on Korea's ECOBEE, an urban magnetic levitation train. Professor Lin Guobin of Tongi University and Professor H. Osaki of the University of Tokyo are also gratefully acknowledged for supplying information on the status of magnetic trains in China and Japan.

Finally, the authors would also like to thank Dr. Peter-Juergen Gaede, Mr. Mizro Iwaya, and Dr. In-Kun Kim, who are developers, for their encouragement and guidance of this work thanks to their own extensive experiences with Transrapid, Linimo, and UTM developments, respectively.

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