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Propulsion of Magnetic Levitation Train

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ABSTRACT

This paper discusses the propulsion technology of magnetic levitation train from an electrical engineering point of view. It also highlighted the potential of maglev train in developing country like Nigeria with an emerging economy in the African region. The engineering challenge for fast, efficient and reliable transportation system is increasing throughout the world but there is very little political or even academic support for the development of a new transportation system in developing countries.

Keywords: Magnetic Levitation, Linear Motor, Permanent Magnet, Linear Induction Motor, Linear Synchronous Motor.

1. INTRODUCTION

The propulsion of a magnetic levitation (Maglev) train is caused by a linear motor. In 1914, Bache let had the idea of using a. c excited coils for levitation and propulsion and not until 1950s that maglev got a real start. The heart of a maglev system is magnetic configuration which support and propel maglev vehicle at designed speeds. In essence, a maglev system is a linear magnetic machine. The maglev receives its propulsion force as in linear motor, which is different from a conventional rotary motor.

The history of linear motor (LM) may be traced back at least as far as the 1840's to the work of Charles Wheatstone at King's College London [1];[2]. Because of their overwhelming simplicity and reliability, LM has long been regarded as the most promising means of propulsion for future high-speed ground transportation systems [3]. The proposed system, while not strictly qualifying as high-speed, still derives so many advantages from the utilization of a LM that no other propulsion means is being considered at this stage. For maglev application, two specific configurations of LMs are considered: the short-stator linear induction motor and the long-stator linear synchronous motor.

It is appreciable that maglev has the tendency of becoming the global transportation system for the near future. It is necessary to be concerned and understand the technologies of the propulsion subsystem of maglev system; this paper discusses the magnetic propulsion technology.

2. MAGNETIC PROPULSION TECHNOLOGY

The principle of operation of a linear motor is such that it produces a straight motion, they operate very similarly to rotary ones [4]. In fact, there is at least a kind of linear motor for every kind of rotary. Like rotary machines, linear ones consist of a moving part and a stationary part, the mover and the stator respectively. Either the mover or the stator becomes the armature by generating a magnetic field that travels linearly. The other part of the motor is known as the field [5].

The propulsion of a maglev train is caused by a linear motor. A linear motor can be described as a rotary motor that has been 'cut open.' In a regular direct current (d. c.) motor a rotor, stator and commuter can be found. The same elements are present in the linear d.c. motor, however its have been cut open, unwrapped and flattened out. The result is a magnetic track, alternating between north and south poles along its length; a solenoid that is being propelled along the track; and a commuter causing the solenoid to change poles in time. It is also possible to switch the rotor and the stator. In this case the track changes poles and the solenoid on the train can be replaced by a permanent magnet. There are the two basic principles of a linear motor and hence the propulsion of the maglev trains.

The forces in a linear motor are either electro-dynamic or electromagnetic [6]. Within the first class are forces also known as Lorentz type forces which are caused by inserting current-carrying conductors in magnetic fields as well as those caused by the interaction between a magnetic field and its reactionary field generated by induced currents [7]; [3]. On the other hand, electromagnetic forces are caused by the interaction between the armature's travelling magnetic field and the field's non-uniform magnetic properties [2]. Because of their planar nature, flat linear motors produce either thrust (or propulsion force) collinear to the travel, and a normal force perpendicular to the thrust [9]. While the thrust is caused by the travel of the armature's magnetic field, the normal force depends on the structure and composition of the motor [10]; [11]. In general, this normal force has two components:

a) A repulsive force caused by the interaction of field's and armature's magnetic fields, and
b) An attractive force between the permanent magnets and the ferromagnetic cores.

When normal forces are present, motor designers usually fix the air gap length by employing linear bearings, electromagnetically controlled suspensions, or air bearings. As mentioned before, the occurrence of these forces depends on the motor's structure, which determines its principle of operation. This principle of operation defines several categories of motors, i.e., induction, synchronous, and direct current.

3. MAGNETIC PROPULSION TYPES

The most natural propulsion system for a magnetically levitated vehicle is a linear motor that uses magnetic forces to produce thrust, which is different from the conventional rotary motor. Its structure is simple and robust as compared with rotary motor, it is conventional rotary motor whose stator, rotor and windings have been cut open, flattened and placed on the guide way. The mode of operation classifies the type of propulsion principles of the train.

A. Propulsion by Linear Induction Motor

In a linear induction motor (LIM), as in rotary induction motors shown in Fig1, the armature constitutes the primary winding and the field the secondary winding, i.e., the armature (the primary) is externally excited and its magnetic field induces currents on the field (the secondary) windings [12];[13]. The primary windings are distributed such that, when excited by a polyphase supply, they generate a travelling field that has forward, backward, and pulsating components. The secondary is either a metallic cage or a short-circuited three-phase winding. In less usual configurations, the secondary could be a piece of laminated or solid iron, a continuous variable reluctance structure, a conducting plate backed [13]

In any case, the currents that the primary magnetic field induces into the secondary generate a reactive magnetic field. The interaction of these two fields produces a motion that can be controlled by regulating the phase of the primary's currents [14]. Conventional systems based on LIMs regulate the armature currents to control thrust, speed, or position and use bearings to restrict motion into the longitudinal single degree of freedom [5]. Nevertheless, recent research showed that LIMs could simultaneously provide propulsion and suspension. There are two types

i) Short primary type: stator coil are onboard and conducting sheets on the guide way.
ii) Long primary type: stator coils are on the guide way and conducting sheets on board.

However, the intensity of this flux also determines the magnitude of the thrust; thus, independent control of thrust and normal force requires combined power supplies that feed the primary with two different frequency components simultaneously. While a low frequency component provides both thrust and normal force, a high frequency one affects only the normal dynamics. Besides requiring complex drivers in order to achieve levitation, LIM suffer from strong cogging forces, which are undesired forces that produce oscillations and are not considered by conventional models. The LIM was developed and utilized for urban transport in Japan [9]. It was also used by Bombardier transportation in advanced rapid transit (ART) system to access New York's JFK international airport [15]. Similar systems are operating in Malaysia and Canada.

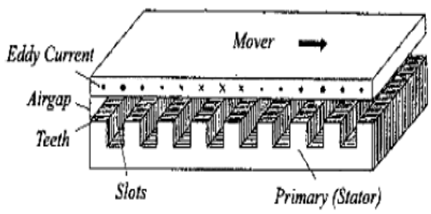

Figure 1. Linear Induction Motor (Hyung-woo Lee et al, 2006)

B. Linear Synchronous Motor Propulsion

Unlike the LIM, the linear synchronous motor (LSM) has the magnetic source within itself as shown in Figure 2. The motion of a LSM is in synchrony with a travelling magnetic field produced by a polyphase armature that is excited by either AC or switched currents. The field can be a variable reluctance structure or an arrangement of permanent magnets. In this system the levitation – propulsion modules are located on each side of the vehicle. Each module contains the exciting field magnet of the LSM that also serve as the levitation magnets that pull the vehicle up to the LSM stator magnet pack attached to the guide way.

In order to reduce operational losses and for stability of the power supply, the system is separated into a number of section controlled by the section switches [13]. The minimum length between two sections depends on the required acceleration and length of train. The vehicle is lighter, because stator winding and power equipment are located wayside. This permits the operation at high-speed (up to 500km/h).

One disadvantage of the LSM drive is that it requires data for the exact position of the on-board magnets to ensure that the vehicle is synchronized with the travelling magnetic wave generated by the stator winding in the guide way [16]. Three common types of LSMs result from the combination of the above kinds of excitation with these choices of fields, namely, Linear Variable Reluctance, Linear Switched Reluctance, and Permanent.

LSM drives with electromagnets were developed, the section of LSM is shown in Figure 2, and is utilized for the German Tran rapid maglev system [17]. This system has been tested in Emsland, Germany since 1984 and is now applied to 30km Shanghai Pudong airport connecting to city-centre [4].

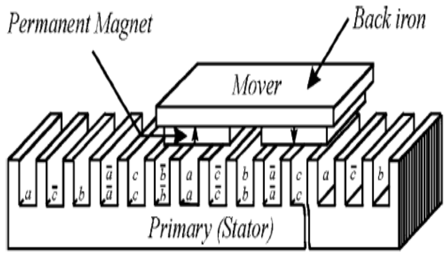

Figure 2. **Linear Synchronous Motor (Hyung-woo Lee et al, 2006)**

C. Propulsion by Permanent Magnets

Permanent magnets (PM) have been successfully applied to linear synchronous drive for automated transfer machine and transportation systems in factories [1];[18]. Their application to propulsion maglev transport system has been done for study and test operations, both as the linear synchronous and as linear induction types [6]

Permanent Magnet Linear Synchronous Motor (PMLSM), in which an array of permanent magnets composes the field. In this case, thrust results when the field of the magnets tends to align itself with the travelling field of the armature. If, besides thrust, an attractive normal force is desired, the armature incorporates ferromagnetic material in its core. The attraction between the core and the magnets produces a normal force that is strong enough for levitation. If the design capitalizes on this attractive force, smaller armature currents are required. And this has been used in factory automation and robotic equipment. This is because of the high-energy efficiency and high thrust force, which makes high-speed operation possible [19]

4. THE FUTURE OF MAGNETIC PROPULSION

The increasing attention in the applications of linear electric motor theory has brought interest and challenges for the development of maglev. The maglev train has been studied and developed from the 1960s, the German, China and Japanese maglev trains have reached industrial levels and test track are experienced. In the 1990s, the USA induct rack, the Swiss swissmetro, and Korea's UTM have been intensively studied and some component prototypes have been built. The transrapid in Shanghai, China and HSST in Nagoya, Japan have been in public service since December 2003 and March 2005, respectively. The Japan's Maglev train sets speed of 374mph in first quarter of 2015, while the China's Maglev train remains the fastest in service with a speed of 268mph.

An efficient and effective transportation system is a basic necessity for higher national productivity. The traffic in most developing countries such as Nigeria has reached chaotic condition leading to frustrations, delay greater accident occurrence and degraded environment. This restricts business growth over the whole economic system, and creates impediments to foreign investors.

Maglev transportation system is a potential future option in developing nations to provide effective daily return transportation for rural dwellers to work in urban and congested cities of about 500km distance or more. The engineering challenge for fast and reliable transportation system is increasing throughout the world but there is very little political or even academic support for the development of a new transportation system in Nigeria. A personal opinion is that the area have unrealized potentials for this country.

CONCLUSION

The need for a new and better transportation system has encouraged many countries to be interested in and attempt to develop the maglev train. However, even though the maglev train has been studied and developed for about a century only a few countries have the knowledge and expertise to do so. This paper discusses the propulsion of maglev train from an electrical engineering point of view. And it will also be helpful for those who are interested in maglev as a viable potential transportation option of the future.

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