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Electrical motors in the lift systems: a review

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ABSTRACT

This paper discussed a few type linear motors for lift systems applications. First, a few types of lift systems are generally presented. Based on these types of lift systems, the common actuators used to operate the lifts are compared and analyzed. Basically, in traditional lift systems, rotational motors are commonly employed as actuators. However, to achieve simpler lift systems, linear motors are utilized instead of rotational motors in direct drive systems. There are three types of linear motors usually being adopted which are linear induction motors (LIM), permanent magnets linear synchronous motors (PMLSM) and switched-reluctance linear synchronous motors (SRLSM). LIM exhibits a simple structure but relatively have low performance, while the SRLSM demonstrates a similar simplicity yet delivering improved performance compared to the LIM. On the other hand, the PMLSM, despite its high-performance capabilities, suffers from notable cogging.

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1. INTRODUCTION

Vertical transportations have become one of the essential things in human daily lives. They help to move people and goods from one floor to another especially in high-rise buildings. A few examples of vertical transportations are escalators, travellators, lifts, and cranes. These vertical transportations require electrical power to operate. Therefore, they can reduce the usage of human energy. As for travellators and lifts, this type of vertical transportation is convenient for people with trolleys and wheelchairs. However, compared to lifts, travellators can usually be found in a shopping mall instead of residential buildings. On the other hand, lifts can be found in most multilevel buildings either business buildings or residential buildings.

In a multilevel building, there is a regulation that requires the developer to provide lift to the physically handicapped people especially in a building that is impractical to construct and build a wheelchair ramp [1]. In Malaysia, there are a few Malaysian standard codes of practice on access for disabled persons that specifies the basic requirement of buildings and related facilities to permit access for disabled persons [2]. Apart from a person with a wheelchair, the lift can also help elderly people and obese people to easily move in a multistoried building. Early lift systems relied on DC series motors with high starting torque capability [3]. However, induction motors (IM) started to replace DC motors in lift system applications as power electronics and the ability to control AC motors advanced. In this paper, a few types of AC motors that are commonly used in lift system applications are discussed.

2. TYPES OF LIFT SYSTEMS

The electrical lift system basically can be divided into three major categories which are geared traction systems, gearless traction systems, and direct drive (ropeless) systems. Traction systems can also be designed with machine-room or machine-roomless for both geared and gearless systems [4]. Depict its name, the roomed type requires separate accommodation of motor room meanwhile roomless type requires only minimal space for motor installation. In general, lift systems consist of the lift car, electrical motor, sheave, ropes and counterweight, control system as well as installation room. The summarization for each type of lift system is shown in Table 1.

In the geared traction system, the motor is attached to the gearbox that is used to turn the hoisting sheave and move the rope [5]. Geared traction lift system basically is used for mid-rise to high rise applications. This type of lift system also has high or variable speed operation [6]. Geared traction lift system can be considered the most traditional lift system in the lift industry.

Similar to geared traction system, a gearless traction system requires a counterweight to balance the weight of the lift car. However, in this system electrical motor is connected to the control system and directly transmits power to the sheave [7]. Despite their higher cost, gearless traction systems consume less energy than geared traction systems making them more efficient in high-rise buildings applications [6]. Apart from that, the elimination of the gearbox reduced space for motor installation.

In contrast to the geared traction lift system, the direct drive lift system also known as rope-less lift systems are considered the newest type of lift system. This type of lift system eliminates the tractions in their systems [8], [9]. Thus, this type of lift system does not require a counterweight to balance the hoisting ropes. With the elimination of the traction system and counterweight, the lift car moves up and down by being directly attached to the mover of the linear motor [9]. Based on this operation, this type of lift system has a more compact design.

Table 1. Electrical lift systems

	Geared traction	Gearless traction	Direct drive
Main components	Electrical motors (rotational) Gearbox Lift car Cable Pulley/sheave	Electrical motors (rotational/linear) Lift car Cable Pulley/sheave	Electrical motors (linear) Lift car
Applications	Low-rise buildings Mid-rise buildings	Mid-rise buildings High-rise buildings	High-rise buildings
Advantages	Low cost Variable speed	High speed Higher efficiency and space saving compared to geared traction systems	Higher efficiency Higher speed
Disadvantage	Environmental unfriendly Low efficiency Noise and vibration High energy consumption	Noise and vibration	High cost Complex assembly process
Remarks			Requires more than two motors for a single lift car [10], [11]

3. LINEAR MOTORS AS LIFT ACTUATORS

In the design of the electrical lift systems, the electrical motor is used to drive the lift car. Depending on the design of the lift system, the electrical motor used may be either a rotational motor or a linear motor as depicted in Figure 1. For instance, only linear motors are eligible to power the direct drive lift systems to move the lift car up and down [8], [9], [12]. As for the conventional lift systems such as traction geared lift systems, the application of rotational motor [13] is required as the main operation driver. The same condition can be seen in the traction gearless lift system [14]–[16] where the main electrical motor used is a rotational motor.

Generally, electrical motors in the application of lift systems can be divided into two major categories. They are rotational motors and linear motors. Each motor can be further divided into PM type or non-PM type based on the existence of PM in their structure. Performance-wise, PM motors have higher thrust density compared to non-PM motors. Mostly, the traction lift systems, either geared traction systems or gearless traction systems advocate rotational motors in their systems. In the geared traction systems, the traction motor which is the source of power is coupled to the gear reducer in order to control the speed and torque [17]. This mechanism however reduced the efficiency of the systems. In an attempt to overcome the performances of this conventional systems, the gear reducer is integrated with the motor itself creating a new topology of a gear motor [18].

On the other hand, the rotational traction motors for the gearless traction systems is directly connected to the control system and transmits the power to a sheave. In the gearless traction systems, the rotational AC motors are used due to their higher efficiency and longer life span [6]. However, it is also possible to employ linear motors in the gearless traction systems [19]. By using linear motor in the traction lift systems, the motors act as both traction motors and counterweight [19]. The application of linear motor in a traction lift system not only minimized the accommodation space but increasing the efficiency and the reliability of the systems [19].

Linear motors are known for providing direct linear motion without any motion translations resulting in a simpler and more robust conversion of electrical input into linear motion [9]. Due to this direct linear motion mechanism, linear motors are advocates as the main actuator for direct drive lift systems applications. Direct drive lift systems are proposed as a solution to high-rise buildings applications to eliminate the usage of cables in traction systems [9]. For this applications, linear motors are required to have high thrust density and high control precision [20]. This paper reviews a few common types of linear motors found in the lift systems applications. The review includes the advantages and disadvantages of each type of linear motors as well as their different configurations found in the lift systems applications.

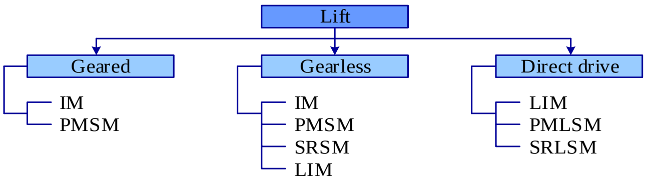


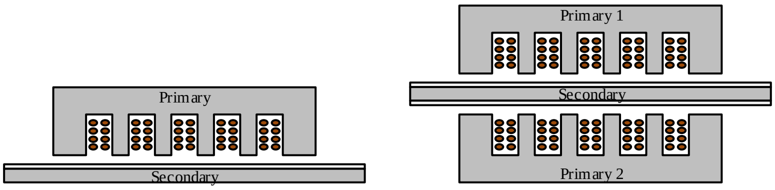
Figure 1. Lift systems and motors classification

3.1. Linear induction motor (LIM)

LIM, like its rotational counterpart, is a common type of motor that is widely used in both the domestic and commercial industries [21]–[24]. A few advantages that contribute to the widespread of LIMs applications in industries are their simple structure, easy manufacturing, and high reliability. Nevertheless, LIMs also suffer from a few shortcomings that degrade their performances. One of the factors is due to their open structure. For example, to avoid the collision between stator and mover during operation, they have a larger air gap compared to the IM, resulting in a low power factor and low efficiency. Apart from that, due to the open iron core, they are affected by end effects phenomenon [25]–[28], such as transversal edge effect and longitudinal end effect.

LIMs can be designed in many topologies with a variety of parameters. Changing one parameter may have the opposite effect and different sensitivity on different output characteristics [29]. Since each topology has its outputs and specialties, the applications will determine the adopted structure [30]. Therefore, the optimal design of LIMs is a comprehensive study by considering different outputs as objectives [29]. Though LIMs can be divided into a few categories based on their structure configurations [30], two of the major types of LIMs are single-side LIM (SLIM) and double-side LIM (DLIM). They are categorized based on the number of their primary part. The SLIM structure consists of only one primary and one secondary part [31]–[33], meanwhile, DLIM consist of two primary parts placed on both sides of the secondary part [27], [34], [35]. Basic configuration of SLIM and DLIM are depicted in Figures 2(a) and 2(b).

In previous studies [19] and [36], SLIM have been designed for two different types of lift systems applications, respectively. A SLIM was designed for a direct drive lift system application [36]. Meanwhile, in [19], a SLIM was designed for an application of a room less traction lift system. In this lift system, the SLIM acts as a driver as well as a counterweight due to its characteristic of mass.



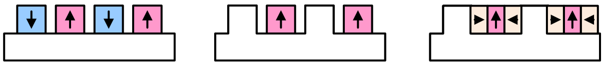
(a) (b)

Figure 2. Basic structure of LIM (a) SLIM and (b) DLIM

3.2. Permanent magnet linear synchronous motor (PMLSM)

PMLSMs are well known for their excellent performances. Due to their high thrust density, high power density, high power factor and high reliability, PMLSMs have been proven to be one of the attractive and potential actuating sources for direct drive applications [37], [38]. The performances of the PMLSMs can be influenced by many factors. However, a few of the main factors are arrangement of PMs, air gap length, slot in primary, and material of the core [39]–[41]. Among these factors, the arrangements of the PMs typically have the most of an impact.

Based on the arrangements of the PMs, PMLSMs can be generally divided into surface-mounted PMLSMs (S-PMLSMs), interior-mounted PMLSMs (I-PMLSMs). However, in order to reduce the usage of PMs in PMLSMs structure, consequent-pole PMLSMs (CP-PMLSMs) are proposed. Figures 3(a) and 3(b) shows the comparison between S-PMLSM and CP-PMLSM. In CP-PMLSMs, the PM is set between two salient ferromagnetic iron poles, where the magnetic direction of all the PMs are the same. This configuration can save half the number of PMs used in the PMLSM structure. Since they can save half the PM material on the long secondary, CP-PMLSMs have been shown to be particularly cost-effective in long stroke applications like the Maglev train and direct drive lift systems [42]. Apart from that, by combining the features of high PM utilization in the CP-PMLSM and high flux density in Halbach array, a new topology of PMLSM known as Halbach consequent-pole PMLSM (HCP-PMLSM) is developed as shown in Figure 3(c).



(a) (b) (c)

Figure 3. PMLSM's secondary with different PM arrangements (a) S-PMLSM, (b) CP-PMLSM, and (c) HCP-PMLSM [42], [43]

Xu *et al.* [43] proposed HCP-PMLSM which has great potential for direct drive lift systems application. In this paper, the authors compared three types of PMLSMs which are S-PMLSM, CP-PMLSM, and HCP-PMLSM. Initially, due to higher PM volume (quantity), the S-PMLSM produced the highest thrust, F with the lowest thrust ripple. However, through pole optimizations and thrust ripple suppression, the authors be able to improve the performances of the proposed HCP-PMLSM. In the final results comparing three types of PMLSMs, it shows that the proposed HCP-PMLSM can produced higher thrust at lower thrust ripple compared with S-PMLSM and CP-PMLSM as depicted in Table 2.

Table 2. Final performance comparison of the three PMLSMs [43]

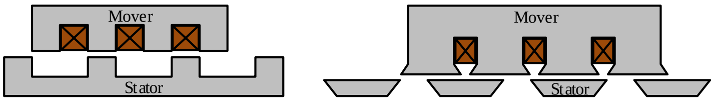
Parameters	SP-PMLSM	CP-PMLSM	HCP-PMLSM
PM volume (cm^3)	492.8	246.4	360.36
Average thrust (N)	2372	1805	2499
PM utilization coefficient (N/cm^3)	4.81	7.33	6.94
Thrust ripple (%)	1.54	3.73	0.87

3.3. Switched-reluctance linear synchronous motor (SRLSM)

The SRLSM's basic configuration consists of toothed structures on both the primary and secondary sides. The primary side includes windings, whereas the secondary side does not require either PM or windings. Because of its simple structure and low material requirements, the SRLSM is very easy to manufacture and thus has a lower manufacturing cost [44], [45] when compared to other motor types. Apart from that, their inherent robustness and broad constant power operating range are a few additional features that contribute to their advantages and made them an interesting candidate in many applications [46], [47].

In the past few years, the researchers have been studied a new topology of the SRSLM which is the SRLSM with segmented primary and/or secondary [48]. According to the study by Wang *et.al.* [20], [49], and Higuchi *et. al.* [50], the segmental type SRLSM (SSRLSM) can produce higher thrust density compared to the conventional SRLSM. This SSRLSM can be designed with a stator pole width to stator pole pitch ratio of almost 1, much higher than 0.5 which is the limit for the conventional SRLSM. This condition increased the overlap area between the mover tooth and stator tooth, therefore the SSRLSM may carry more flux and have more co-energy at the same magnetic load yet uses fewer windings to produce the same flux. Figure 4 shows the basic structure of two different types of the SRLSM.

In the lift systems application, the SRSLM is normally used in the direct drive lift systems [11], [20], [51]. The direct drive lift systems require a driving actuator that can produced high thrust density in order to directly move the lift car without the traction systems. Therefore, in designing the SRLSM for direct drive lift systems, a few features that need to be considered are the weight of the mover and the thrust density. In order to design the appropriate SRLSM for the direct drive lift systems, the weight of the mover need to be minimized where the thrust density need to be maximized [52].



(a) (b)

Figure 4. Basic structure of SRLSM (a) conventional SRLSM and (b) segmented SRLSM

3.4. Summary on linear motors

Based on the literatures, a few types of electrical motors applied in the lift systems are discussed. In general, the non-PM linear motors such as LIMs and SRLSMs have lower cost compared to the PM linear motors. However, the existence of the PMs in the linear motors' structures increases their thrust density despite having higher manufacturing cost. In a nutshell, each type of linear motors has their own advantages and disadvantage. The advantages and disadvantages of each motor types are summarized as in Table 3.

Table 3. Types of linear motors

Criteria	Non-PM		PM
	LIM	SRLSM	PMLSM
Structure	Consist of stator and mover. Very similar to SRLSM.	Consist of teethed structure on both stator and mover side. Winding on the mover side.	Consist of winding on the primary side and PM on the secondary side.
Advantage	Simple structure Low cost Robust	Simple structure Low cost Easy manufacturing	High thrust density High efficiency Better dynamic response
Disadvantage	Lower power factor Lower thrust density	Thrust ripple Vibration and acoustic noise	Higher manufacturing cost High cogging thrust Possibility of PM demagnetization
Performance	Greatly influenced by two kinds of end effect; transverse edge effect and longitudinal end effect	The thrust is generated by a variation of self-inductance	Can be affected by structure parameters such as PM sizes, PM arrangements, and air gap length

4. CONCLUSION

Over the years, lift systems technology has undergoing a lot of improvements since their first invention. Geared traction system was replaced by gearless traction system to increase the performance and efficiency. Then, the roomed gearless system is improved by room-less system to reduce the installation space. Further, the traction system is to be replaced by direct drive system for higher buildings applications and so on. All of these are some of the improvements that involve in the research of the lift system applications. These improvements are necessary in order to fulfil the consumers' needs in providing lift systems with better quality ride.

Based on the discussions, a traction lift system operates by linear motor for a domestic lift application is a viable option. In that aspect, the SRLSM can be considered to be a good candidate to operate the lift system. Compared to the LIMs, SRLSMs have higher performance despite their simple structure. Apart from that, SRLSMs operate without the use of permanent magnets, allowing them to handle high current operations. Moreover, because SRLSMs are not dependent on permanent magnets, there are no concerns about their availability or cost, making them an appealing choice for domestic lifts. Though SRLSMs might suffer from thrust ripple, high noise and vibration, they can be reduced either by control methods or designed methods.

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