A New Linear Switched Reluctance Motor with MagLev Effect

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Abstract

This paper presents the design of a new linear switched reluctance motor (LSRM) structure. The new model has a triple sided configuration for high force density and provides MagLev (Magnetic Levitation) effect to reduce friction force by decreasing the normal force generated in the system. Characteristics of the LSRM are obtained by using finite element analysis (FEA) and analytical method. The new motor structure is very suitable for many applications with low cost, especially for high speed railway transportation systems.

1. Introduction

There has been an increasing interest in the switched reluctance motor (SRM) drives recently. The numerous advantages of the SRM make it an attractive solution for many industrial applications. Some advantages of the SRMs are robust construction, low cost in mass production, reduced maintenance requirements, fault tolerance, high efficiency, rugged behavior, and large torque output over very wide speed range [1, 2]. However, the available literature seems to concentrate on the rotary switched reluctance motor (RSRM), leaving the linear version of the SRM largely unexplored [1-10].

Linear switched reluctance motor (LSRM) is a type of direct drive motors. There is an increasing interest in direct drive systems with continual development of power electronics and control strategies. All types of direct drive motors have some advantages such as simple control, fast response, high speed and high acceleration. In addition, LSRMs have advantages of simple structure, high robustness, and no expensive magnets when they are compared with other types of linear motors. The motor contains only laminated steel sheets and phase windings.

The LSRM presented in this paper has a triple stator structure with three phases and windings located on the translator (stator platform). Mass production cost of the complete LSRM system is low, because phase windings are located on the translator. Produced forward (propulsion) force of the LSRM is also higher than those of other linear structures because of its stator blocks. In addition, the new motor reduces normal force because of its novel structure.

This paper contains the illustration of design and analysis procedures of the proposed motor. The analysis procedure of the motor is realized with the use of finite element analysis (FEA) to calculate the magnetic characteristics of the motor accurately. In addition, an analytical method is used to calculate inductance profile of the proposed structure. The needed values for the analytical calculation are taken from FEA.

In this paper, Section 2 gives the topology of the proposed LSRM and its basic operation principle is described in detail. Section 3 covers the analytical and FEA calculations of the motor characteristics. Section 4 gives a comparison of the results and section 5 presents the conclusions of this study and interpretations about the proposed LSRM structure.

2. Basic Principles of the Proposed LSRM

Fig. 1 shows the construction of the proposed LSRM with three phases in three dimensional form. Excitation windings are located on the stator platform. The main stator parts of the motor to generate propulsion force are placed at the top of the structure and two stator blocks at two sides are used to provide a maglev effect and improve the propulsion force performance.

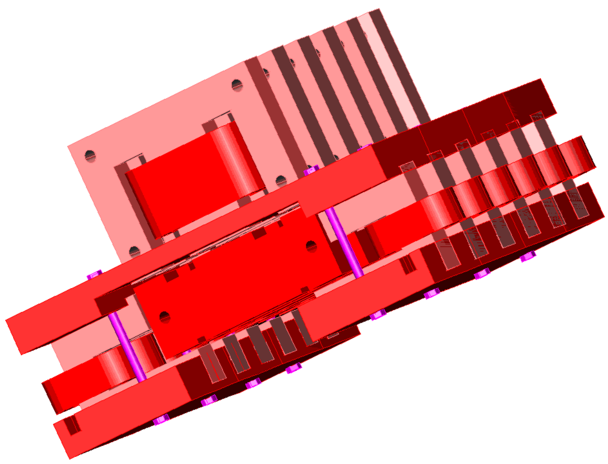

Fig. 1. 3D appearance of the proposed LSRM structure.

The proposed motor structure reduces the mass production cost because windings of the LSRM are located on the translator. In addition, rotor parts as rail parts of the road do not need to be continuous because of flux distribution of the model. Therefore, this motor structure does not have a rotor yoke. The proposed structure also provides high propulsion force because of triple stator structure of the motor.

The basic parameters of the new proposed LSRM structure are summarized in Table 1.

Table 1. Basic parameters of the proposed LSRM.

Phase number	3
Active stator number	3
Stator pole width	16 mm
Stator depth	60-80 mm
Rotor pole width	16 mm
Rotor depth	41 mm
Overall length	240 mm
Overall width	200 mm
Air gap	2 mm
Steel type	M19

3. Obtaining of Magnetic Characteristics of the LSRM

3.1. Finite Element Analysis (FEA)

Finite element analysis (FEA) provides an accurate performance prediction as a more detailed analysis for magnetic modeling of SRMs and LSRMs [8]. FEA techniques are well known, therefore their details are omitted here. M19 steel lamination material is the only nonlinear material in the model used in the FEA.

The problem is formulated at a constant current excitation. By changing the level of the excitation current and moving the translator, static force, inductance and flux linkage can be obtained as a function of position and current. The excitation current levels are selected to be in 2.5A, 5A, 15A and 25A. Flux distribution of the motor for the aligned position is shown in Fig. 2.

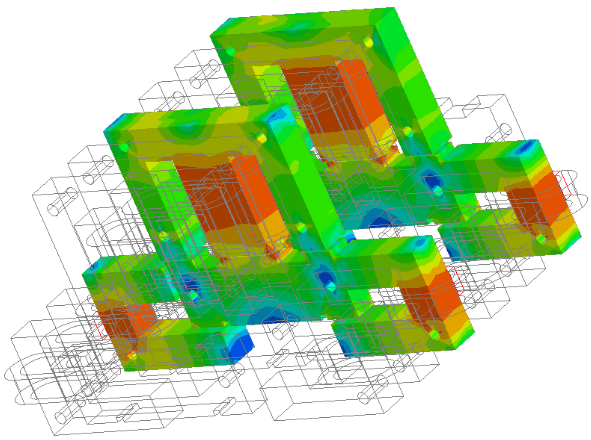

Fig. 2. Flux distribution of the LSRM at the aligned position.

3.2. Analytical Calculation of Phase Inductance

In this paper, a very simple analytical method is used to calculate the phase inductance of the motor This method, which represents the functional relationship between the rotor position, phase current and phase inductance, is given in detail in [9, 10]. In this model, inductance variation of the motor versus the rotor position is represented using the Fourier series with only the first three terms considered. The model for the one phase of the motor is given by

$$L(i,x) = L_0(i) + L_1(i)\cos(N_r x) + L_2(i)\cos(2N_r x) \tag{1}$$

where N_r, x and i are the number of rotor poles, rotor position and phase current, respectively. In addition, L_0, L_1 and L_2 are given by

$$L_0(i) = \frac{1}{2}\left[\frac{1}{2}(L_a + L_u) + L_m\right] \tag{2}$$

$$L_1(i) = \frac{1}{2}(L_a - L_u) \tag{3}$$

$$L_2(i) = \frac{1}{2}\left[\frac{1}{2}(L_a + L_u) - L_m\right] \tag{4}$$

In the equations, L_a, L_u and L_m are the inductance values at the aligned, unaligned and midway positions.

It is shown clearly that the development of the above inductance model only requires three inductance values at the aligned position, unaligned position and midway between the aligned and unaligned position. In this study, these three values are obtained from the FEA.

4. Results

In this study, analytical calculations and FEA are used to obtain magnetic characteristics of the LSRM. The active translator of the LSRM is moved from the unaligned position to aligned position for different excitation currents.

Normal and propulsion force values obtained at the unaligned, midway and aligned positions of the proposed motor and classical LSRM with the same sizes are compared for different phase currents and are given in Table 2 and 3, respectively. The classical LSRM does not have any stator blocks in both two sides of the motor.

Table 2. Comparing of normal force values of the proposed and classical LSRM structures with the same sizes.

Phase Current (A)	Normal Forces of The Proposed Motor Structure (N)			Normal Forces of The Classical LSRM Structure (N)			Amounts of Normal Force Decrement (%)		
	Unaligned	Midway	Aligned	Unaligned	Midway	Aligned	Unaligned	Midway	Aligned
2,5	0,2	3,99	8,88	1,7	6,68	13,92	88,24	40,27	36,21
5	0,7	17,02	36,97	7,8	28,60	57,65	91,02	40,49	35,87
15	8,01	145,39	298,02	62,97	244,66	463,04	87,28	40,57	35,64
25	21,47	291,64	502,96	150,56	485,02	784,60	85,74	39,87	35,90

Table 3. Comparing of propulsion force values of the proposed and classical LSRM structures with the same sizes.

Phase Current (A)	Propulsion Forces of The Proposed Motor Structure (N)			Propulsion Forces of The Classical LSRM Structure (N)			Amounts of Propulsion Force Increment (%)		
	Unaligned	Midway	Aligned	Unaligned	Midway	Aligned	Unaligned	Midway	Aligned
2,5	0,007	2,04	0,004	0,007	1,48	0,018	0,00	37,83	-77,77
5	0,043	8,32	0,5	0,017	5,94	0,38	152,9	40,06	31,58
15	0,44	72,92	0,32	2,21	53,46	0,44	-80,09	36,40	-27,27
25	0,88	145,15	0,70	4,93	108,89	0,80	-82,15	33,30	-12,50

The new LSRM structure improves the propulsion force capability and decreases the normal force of the classical LSRMs as given in Tables 2 and 3. Although decrement of the normal force between the classical and proposed LSRM structures can reach 91,02 % at the unaligned position, this amount can be neglected, because the normal force is minimum at this position. Therefore, the main advantage of the new structure should be investigated at the aligned position for the normal force decrements. So, the minimum normal force decrement provided by the new structure is 35,64 % when compared to classical structure as given in Table 2. This situation is also valid for the improvement of the propulsion force generation except of the changing positions. Results obtained at the midway position should be evaluated for the propulsion force improvement. So, the minimum improvement of the propulsion force provided by the new structure is 33,3 % when compared to classical structure as given in Table 3.

The inductance profile of the proposed structure obtained with the use of analytical method detailed in section 3 is shown in Fig. 3.

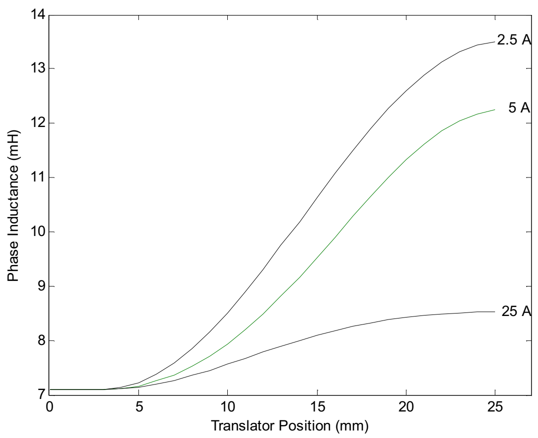

Fig. 3. Phase inductance profile of the proposed LSRM.

5. Conclusions

In this study, analysis and design of a new triple stator LSRM structure are discussed. Obtained results show that propulsion force values of the proposed structure better than those of the classical LSRM. In addition, the new structure decreases the normal force owing to MagLev effect with low cost. The proposed structure can be used in many applications but especially in transportation systems as a direct drive system. Prototype of the proposed motor will be realized for experimental studies as soon as possible. LSRM drives with numerous advantages may be strong competitor for direct drive applications such as high speed railway transportation in the future. Future research will continue to develop LSRM technologies for relevant applications.

6. References

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