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Design and analysis of a double sided linear switched reluctance motor driver for elevator door

***Abstract**. In this study, an electromagnetic design of double sided linear switched reluctance motor (LSRM) is presented. It has been designed for driving an elevator door. The motor has tree phase and 6/4 poles. The motor's magnetic analysis was done as a 3 dimensional model. The parameters like magnetic forces, magnetic flux regarding to rotor positions and motor excitation currents were obtained statically with help of the finite element methods and Ansoft Maxwell 13.0 software. The motor's physical sizes were obtained as mathematically.*

***Streszczenie.** Przedstawiono projekt dwustronnego liniowego silnika reluktancyjnego przystosowanego do obsługi drzwi windy. Wykorzystując metodę elementu skończonego i program Ansoft Maxwell obliczono siłę magnetyczną, strumień magnetyczny dla różnych położeń wirnika oraz prąd zasilający. (**Projekt i analiza dwustronnego silnika reluktancyjnego przystosowanego do obsługi drzwi windy**).*

Keywords: Linear switched reluctance motor, finite element analysis, automatic door driver, elevator door.
Słowa kluczowe: silnik reluktancyjny, metoda elementu skończonego.

Introduction

To In the places where there has been a heavy traffic jam over elevators, subways, and trains, the automatic sliding door systems must be opened as comfortable and must be prevented unauthorized entering because of security reasons. Opening and closing time of automatic door systems will significantly affect waiting time of passengers. Besides, having the advantage of heat saving in winters, it also has the advantage of letting only the authorized staff into such working areas. The performance of these systems depends on the performance of the driver and the structure of the motor used to drive the door mechanism.

The simple structure of LSRMs provides high pushing-pulling force with the low cost, speed gaining and sensitive position control [1]-[3] Because of these features; it will significantly raise the performance of the door mechanism in the use of automatic doors.

However, as the sliding door systems are not standard, it obliges people whom design motors to do an optimum door drive motor which would force the door by pulling.

There are a lot of studies in literature about modeling, analysis and design of the rotary switched reluctance motor (RSRM), although there is paucity on linear switched reluctance motors (LSRMs). Two distinctive configurations have been proposed as transverse and longitudinal flux LSRM in the literature. However, designing these LSRMs are not described in detail, calculation of the magnetic characteristics of the motor is covered extensively in literature [1]-[6], [7]-[9], [12], [15]. Tarimer and et al., designed and analyzed a 1 kilo Watts longitudinal flux permanent magnet linear synchronous generator in electromagnetic way [10]. They inferred that magnetic parameters which define generator characteristics have been obtained accordance with the required needs.

The force to be applied to the elevator doors has been accepted in different standards values according to countries. The door standards make the drive force to be applied to the door be kept in designated boundaries.

In this study, a LSRM which can be used in an elevator door, and which can be directly driven has been designed and magnetic analyses of this motor have been done. The motor is fixed to the valve and can make the door to move without a belt, pulley or a reducer. In the first phase of this design power of the motor is assigned as 0.15 HP. Therefore it was estimated that the designed LSRM to produce a pulling force of 250 N in x-axis (horizontal axis). This value is sufficient to drive the door directly for the elevator door used in this study and it is appropriate for Turkish standards [13]-[14].

According to the estimated basic parameters, physical size of the motor was calculated analytically [4]. The three dimensional model of the motor was visualized by using computer aided design (CAD) programs towards the results gained. The magnetic analyses of the motor which give the physical size have been done. As known many electromagnetic analyzing software are being used in such these applications [5]-[6]. The software used in this study makes static magnetic analysis with the finite element method.

Automatic door drive

The movement in today's automatic door system comes true with a motor which makes the circular movement and a mechanism installed with the belt system moved by this motor. The belt and the gear system can be easily corrupted and deformed by time. Since the motors do circular movement, there would be a vibration in such systems. Furthermore, in these systems the work should be done fast and correctly. The instruments used should be durable, moving parts and the elements used should be less and the maintenance requirement of the system should be very low.

Because of simplicity of controlling the DC motors and to be able actuate them with analogue circuit elements led DC motors to be used widely even today. Therefore they constitute a crucial place in industry. Alike a DC motor is usually used in trains, subways, elevators and surgery room doors. However, since mechanic parts such as brushes and collectors have high failure rate these motors can't be used in environments which probably have explosion risks. Because of the speed reaction is slow and they can't be used in high speed applications. As result of these, the uses of DC motors are limited. Especially the brush and collector maintenance which need most frequently are very vital in door slide applications. Besides, since DC motor even draws high currents while the elevator is in off position, this can be seen as another disadvantage. The DC motors are preferred solely for those applications where high torque is needed during the first movement (elevator-off).

LSR motors showed a rapid improvement with help of semiconductor technology. Since the speed control range is very large, these motors have found a widespread area of use. They draw a considerable interest in the consumer-wise and industrial applications since they have simple structure, cost and maintenance need [11]. As an alternative to other AC and DC motors, they took place many practical fields in movement control systems. Higher efficiency in the LSRM which can be controlled with an appropriate converter circuit and driving system can be gained rather than the other electric motors [7]. The number of the rotor pole is different than the number of stator poles of these motors and they are brushless DC motors without having any windings in their rotors.

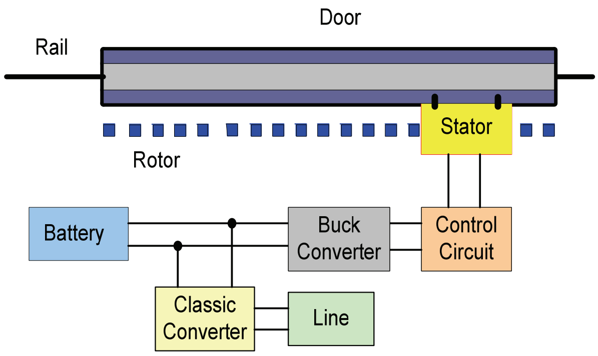

Fig.1. Block diagram of elevator door's driving

LSR Motors are still being developed and put into effect to many applications like elevators and automatic doors which require linear movement [8]. The structure of LSRM is seen in Figure 2, this structure is same with a SRM which moves as rotational.

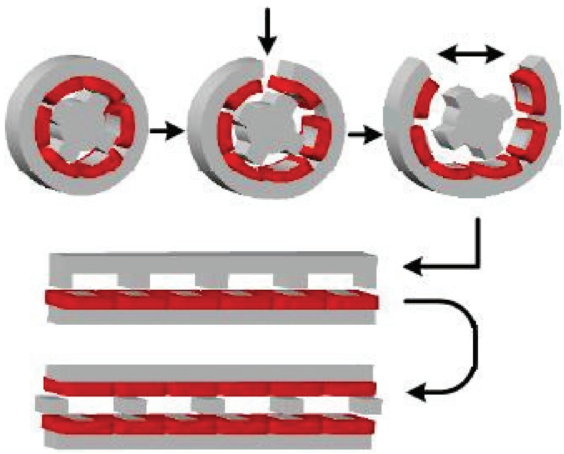

Fig.2. Structure of a Linear Switched Reluctance Motor

Stator poles turn into a big electromagnet when a phase windings in LSRM is energized. The stator poles which turn into electromagnet pull the nearest rotor poles to themselves with an apparent torque. The movement composed continues until the armature poles which were separated at the beginning come to an aligned position. When the rotor pole comes to an aligned position, rotor movement finishes if the energy of this phase isn't cut and next phase wouldn't be energized [9]. The armature torque is bound to the direction of the flux applied to the stator windings, since the magnetizing force of the iron used in the motor poles is independent of the magnetic flux.

Linear Switched Reluctance Motor design

Since switched reluctance motors have salient poles in its stator and rotor, they are assumed as simple motors. The aligned poles of the stator windings are connected parallel to each other in this design. The ones placed as side by side on the same stator core are connected as series. The stator and the rotor in this motor are composed as having one side siliceous. However, there aren't any windings or magnet material in the rotor.

Even though LSRMs are designed as with different poles and winding structures in literature, it has been presented that rotor consists of four salient poles and stator consists of six salient poles for driving door of an elevator in this study. Thus, the number of the switched elements which increase directly proportional with the phase number of the motor is kept at minimum; this is necessary for controlling the circuit [12]. The basic parameters of the design of linear switched reluctance motor for the drive of an elevator are given in Table 1.

Table 1. Basic design values of LSR Motor

Design Parameter	Value
Power	0,15 HP
Nominal Current	5 A
Nominal Force	250 N

According to the values given above, the applied magneto motor force (MMF) for each phase winding of the motor is calculated with the Equation 1;

(1) $$F = F_g + F_s + F_r$$

where, F shows the total motor magneto force for each phase. The terms Fg, Fs and Fr respectively show force gradient in air gap, force gradient in stator core and force gradient in rotor core.

Magnetic field strength can be found with the help of Equation 2 ;

(2) $$F = T_f i = \sum H_g l_g + \sum H_s l_s + \sum H_r l_r$$

where, Tf shows number of turn for each phase winding, i shows the current in the winding. Terms Hg , Hs , Hr , lg , ls , lr show respectively magnetic field strength and flux way length in air gap, stator core and armature core.
Total flux produced in LSR motor's stator is written like this;

(3) $$\varphi_s(i,x) = B_s(i,x).A_s$$

where, Bs(i,x) gives stator pole flux density while passing current (I) and standing in x position; As gives stator pole across.
By using Equation 3 flux density is found. Magnetic field strengths (H) are obtained from the B-H characteristic curve of the metals used in cores. The reluctance of the motor is calculated with the Equation 4; with the help of stator poles, armature poles and magnetic field strengths obtained for the airspace.

(4) $$\Re = \frac{H.l}{\varphi}$$

Inductance of a phase is found out by using total magnetic flux ways in Equation 5.

(5) $$L(i,x) = \sum L(i,x) = \frac{T_f}{i}.\sum \varphi(i,x)$$

By evaluating the results obtained with the analytic calculations related to the geometric dimensions of the motor various enhancements can be done in order to increase the performance on these dimensions.

Magnetic analyses of LSR Motor

Aligned location of the motor windings to two different stator structures is shown in Figure 3. Stator is over opposite with respect to armature and minimum reluctance is shown. In this case if "y" windings are energized, stator will move towards right side as a carrier. If a movement to the other side is desired, “z” windings should be energized.

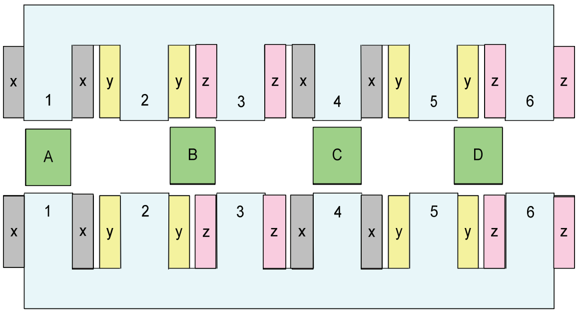

Fig.3. The placement of the stator windings of the LSRM

Stator and armature is designed with the steel material in Steel 1010 characteristic. The B-H curve of the Steel 1010 material is given in Figure 4. The outer part of the model is assigned as air by using copper in the stator windings.

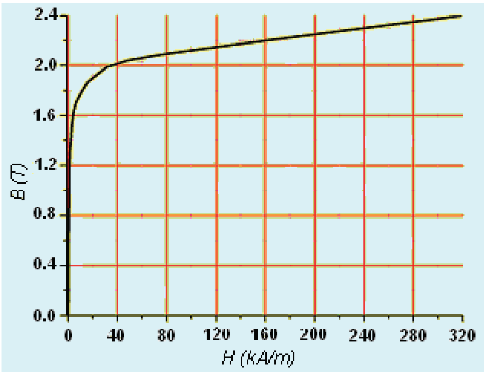

Fig.4. Steel 1010 BH Curve

The appropriate mechanical and electrical parameters for designing the motor are given in Table 2. The motor has been visualized as 3 dimensional upon these parameters.

Table 2. Basic design values of LSR Motor

Design Parameter	Value
Number of Phase	3
Stator Pole Width	20 mm
Stator Pole Gap	23 mm
Stator Pole Height	26 mm
Stator Pole Depth	60 mm
Rotor Pole Width	23 mm
Rotor Depth	60 mm
Total Length	235 mm
Total Width	118 mm
Airspace	0,6 mm
The type of the steel	Steel 1010

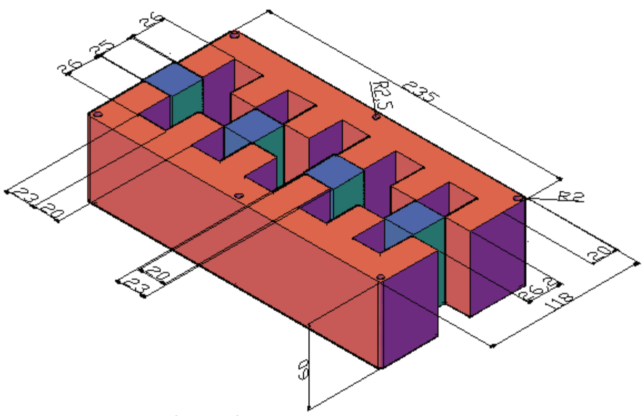
Fig.5. 3-d model of the LSR motor

The 3-d figure of the motor as been drawn with a computer aided design software, and it is shown in Figure 5. The designed motor is transmitted to the simulation phase with software. The induced electro magnetic torque, magnetic flux and magnetic flux with flux density, magnetic flux with flux density vectors are obtained for this design. The obtained values are non-linear functions because they are changed according to the location of the rotor and flux. So, the best method to get the performance analyses of the motor is finite elements analyses. The magnetic analyses were done of the 3-d model of the motor and simulation. It can be seen that the finite elements surface of 3-d model of the motor in Figure 6.

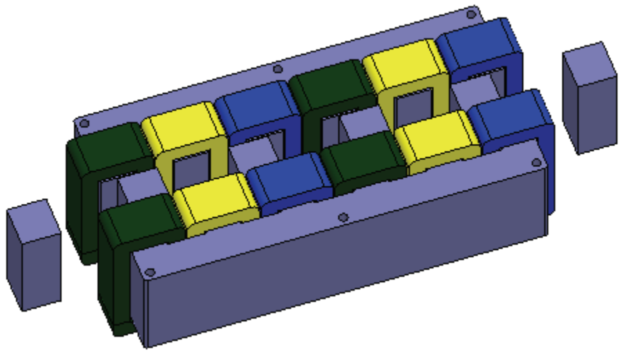
Fig.6. 3-d view of LSRM

The variables in the magnetic analyses of the motor are the location of the armature and winding currents. The software composes the finite elements surface of the motor depending upon the location of the armature and then calculates the basic outlet parameters like phase inductions, moment, force, magnetic flux and flux density. In Figure 7 and Figure 8 aligned magnetic flux density and unaligned magnetic flux density is respectively given.

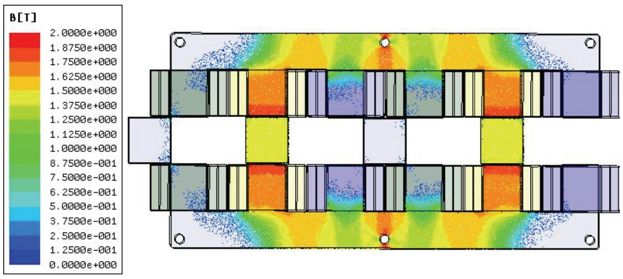
Fig.7. The magnetic flux density at aligned position

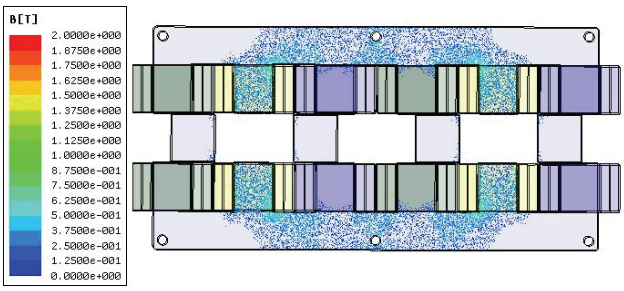
Fig.8. The magnetic flux density at unaligned position

The most important characteristic curves of the LSRMs are armature position-force and winding current-induction alternation. In Table 3 and Figure 9 inductance change and inductance matrix between phases in aligned and unaligned position of the magnetic analyzed motor is respectively given.

Position (mm)	1A	2A	3A	4A	5A	6A	7A	8A
Unaligned (0)	1.46	1.46	1.46	1.47	1.47	1.47	1.47	1.47
5	1.53	1.53	1.53	1.54	1.54	1.54	1.54	1.54
10	1.97	1.98	1.98	1.98	1.99	1.98	1.99	1.98
15	4.34	4.38	4.35	4.19	3.95	3.70	3.36	3.18
20	6.66	6.79	6.72	6.37	5.90	5.34	4.86	4.41
25	8.87	9.02	8.77	8.20	7.43	6.66	5.99	5.41
30	10.83	10.93	10.33	9.31	8.20	7.28	6.46	5.83
Aligned (32.5)	11.20	11.25	10.55	9.41	8.28	7.31	6.50	5.85
35	10.83	10.93	10.33	9.31	8.20	7.28	6.46	5.83
40	8.87	9.02	8.77	8.20	7.43	6.66	5.99	5.41
45	6.66	6.79	6.72	6.37	5.90	5.34	4.86	4.41
50	4.34	4.38	4.35	4.19	3.95	3.70	3.36	3.18
55	1.97	1.98	1.98	1.98	1.99	1.98	1.99	1.98
60	1.53	1.53	1.53	1.54	1.54	1.54	1.54	1.54
Unaligned(65)	1.46	1.46	1.46	1.47	1.47	1.47	1.47	1.47

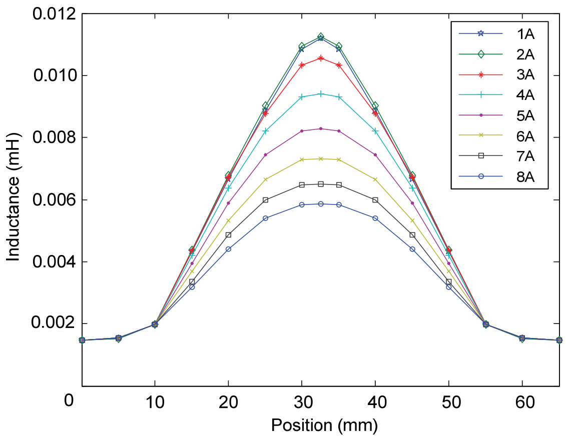

Fig.9. Inductance change

During the magnetic analyzing of the motor designed, 8 A current is applied. In this case, the force obtained in the state of armature is given as Newton in Figure 10. The graphic in the figure shows the force alteration of the stator and armature from the total detached status to the coincident status.

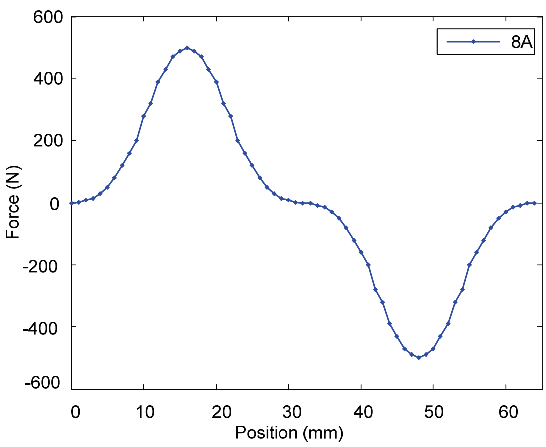

Fig.10. Rotor position-force change

Conclusion

The static characteristics are obtained from this analysis. It is obvious that the performance gained from the designed linear switched reluctance motor is suitable to use as providing elevator door drive. Besides, by making LSRM in different power and positions, this design can be recommended for practical use which requires different linear movements.

In this study, design of a linear switched reluctance motor used instead of classical brush DC motor for elevator door driving and the magnetic analyses were carried out. Force and inductance variables of the magnetic circuit in detached and coincident positions were obtained with the finite elements method. As a result of the performed magnetic analyses it is obvious that the desired outlet gravity was attained. In this case, the result that design of a linear switched motor can fulfill the needs of an elevator door is inferred.

This study is under the supervision and support of 00401.STZ.2009-1 coded SANTEZ project by Ministry of Industry and Trade with EMSA Automation.

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