Design of Linear Switched Reluctance Motor Driver for Automatic Door Application

M. Dursun, F. Koc, H. Ozbay, and S. Ozden

***Abstract*—In this study, a buck converter and a driver has been designed for Linear Switched Reluctance Motor (LSRM) with 6/4 poles, 3 phases, 250W. LSRM controlled by PIC 18F452 microcontroller was used to drive automatic door. Motor was controlled more accurate with linear incremental encoder by sensing acceleration and movement direction of door.**

***Index Terms*—Linear Switched Reluctance Motor, linear motor driver, Automatic door.**

I. Introduction

In earlier stage of automatic doors developments, rotary DC motor which has a high torque was preferred for horizontal movement of door. But induction motor (IM) was become widespread by reason of high maintenance cost of DC Motor's commutator and brushes. However, hysteresis loses of IM couldn't be ignored.

Rotary motion of motor is converted to linear movement with wheel, belt and gear box. These components decrease efficiency of system. Furthermore they increase costs and difficulty of maintenance. LSRM which is cheap and simple mechanical structure has high efficiency push/pull force. When the motor was driven appropriate controller, it is more efficient than DC motor and IM. Also LSRM doesn't need addition equipment such as wheel, belt and gear due to its linear motion naturally. Because of nonlinear magnetic structure of LSRM, its simulation and modeling is rather complex. Efficiency, performance and acquiring smooth push/pull force of motor are related accurate mathematical model.

Today rotational and linear SRM uses different industrial application [1-6]. The present literature about LSRM is focused on application of transportation. R. Krishnan designed a LSRM to drive elevator in 2004. The elevator system with LSRM was applied steadily and he was explained that its cost is 15 times cheaper than other conventional elevators. In [7] and [8], the development of an LSRM is discussed mainly for transportation systems and the control output is velocity [9]. In [10] and [11], a detailed motor design procedure and the motor control algorithm are given and also its control output is again velocity.

In this study a driver has been designed for Linear Switched Reluctance Motor (LSRM) with 6/4 poles, 3 phases, 250W. LSRM controlled by PIC 18F452 microcontroller was used to drive automatic door. Motor was controlled more accurate with linear incremental encoder by sensing acceleration and movement direction of door.

II. LSRM Structure and Driver DEVICE

In the design of LSRM, the following properties are assumed: length of LSRM=0.8 m, maximum linear velocity, v_m =1.0 m/s, acceleration time, t_a = 0.167 s, and maximum mass for translator=25 kg.

In fact, properties of linear motors are not much different than the electrical and geometric properties of rotational motors. Since the length of prototype of motor to be designed is 235 mm, the machine may be considered as a rotational motor with the circumferential of 235 mm and radius 37.40 mm. The motor is regarded for use in opening and closing an elevator door of weight 25 kg at a distance of 80 cm.

Mass of the door (m) is 25 kg, acceleration time (t_a) is selected as 0.167 second and velocity of the door (v_m) is selected as 1.0 m/s. According to these values, the acceleration of the door (a) is found by (1) and the pull force to accelerate the door is found by (2), respectively as

$$a = \frac{v_m}{t_a} = \frac{1.0}{0.167} = 6 \ \mathbf{m/s^2} \tag{1}$$

$$F_a = ma = 25.6 = 150\,\mathbf{N} \tag{2}$$

F_a was selected as 250 N by adding the 100 N force required for the static friction. F_a is the force which the motor should apply to door, m is mass of door (kg) and a is the acceleration determined from (6). Deceleration of the door to stop is equal to its acceleration, but has reverse sign. Accordingly, the LSRM's power (P) is calculated by (3) as:

$$P = F_a v_m = 250.1 = 250\,\mathbf{W} \tag{3}$$

LSRM which has salient poles rotor and translator is simple structure [12-16]. The controlled LSRM is designed as double sided and mutual windings are connected as a parallel. Same phase windings on same side are connected as a serial. Rotor and translator of motor is packed sheet steel with silica. Translator has phase windings; however rotor has no windings or magnet.

Aligned location of the motor windings to two different stator structures is shown in Fig. 1. Stator is over opposite with respect

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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.

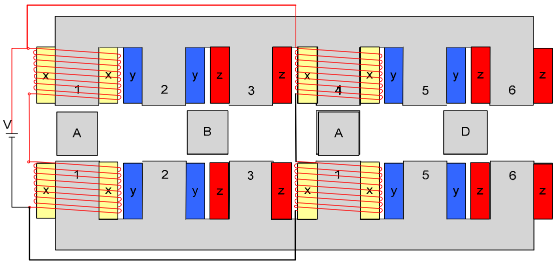

Fig. 1. The placement of the stator windings to linear switched reluctance motor.

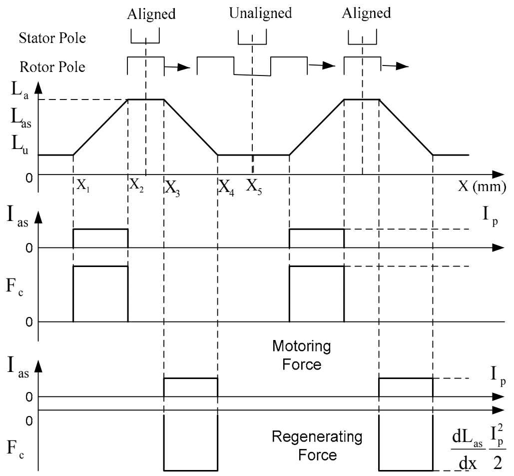

Fig. 2. Inductance profile of 5 sections for the motor versus translator position

III. INDUCTANCE PROFILE OF LSRM

The ideal inductance profile according to translator position of the designed motor has 5 sections. These sections for the motor obtained versus to translator position were shown in Fig. 2. In this section, the minimum and maximum value of Phase A does not change from the initial positions to X_1. Since the inductance positively changes in this section and positive pulling force occurs by ratio of the square of current which is passed through the coil. Since the inducted force varies by the square of the current, it is independent of the direction of current. Section 3 is the section where inductance is maximum. Since inductance variation is zero in this section, derivative of inductance is also zero. Therefore, any pulling force is not produced in this section even if current is applied to the phase coil. In order to decrease the any phase current in coil to zero, phase current should be interrupted before the end of section 2. In this section, current interruption point directly depends on the current value, inductance value and vehicle velocity. In Section 4, the inductance decreases and length of since inductance variation is negative, the direction of force is also negative. So, the motor operates as a generator during this section. Properties of section 4, 5 are similar to that of Section 1. The minimum value of phase inductance of motor is indicated as 0.001472 mH and maximum inductance as 0.005851 mH for 8A. Consequently, electrical properties of the motor are determined as 250 W, 24V DC, 8 A

IV. LSRM CONVERTER CIRCUIT

When a translator pole is energized, the motor force is in the direction that will reduce reluctance. Thus the nearest rotor pole is pulled from the unaligned position into alignment with the translator field (a position of less reluctance). When the rotor moved to aligned position, push/pull force is generated amount of changing reluctance. Current of phase winding is other parameter which effects motor push/pull force. The force is proportional to square of current so it is independent current direction. When sequence of phase switching was changed, motion direction of motor is changed. Feature of converter could affect performance of motor.

There are different type converter topologies to energize phases. The most suitable of them is classical bridge converter. Fig. 3 shows buck+classical converter for LSRM to drive. windings while translator is moving towards unaligned position from aligned position, breaking force is occurred. If there is still residual energy in this disadvantage, windings current must cut off Residual energy in windings is the most important point at prevent before aligned position. Therefore, this cut off time was defined with position and speed information of motor by PIC microcontroller. In LSRM driver circuit and in Fig. 5 view of driver are shown

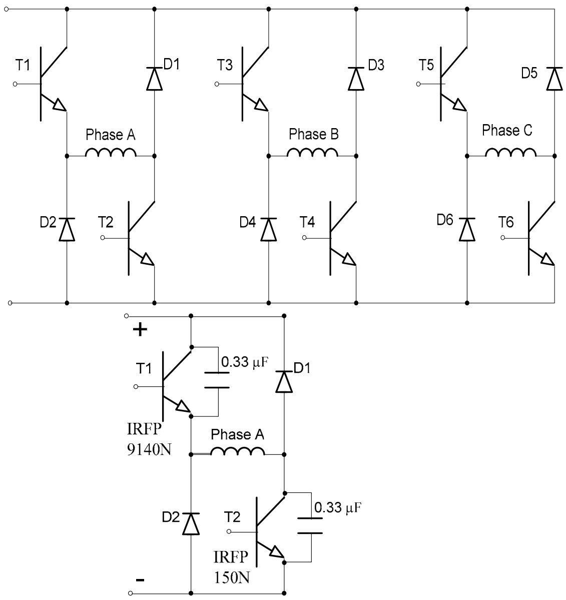

Fig. 3. Three phases classical converter and snubber device for LSRM.

V. LSRM CONTROL

Control block diagram of LSRM is shown in Fig. 6. Position data and current values are sensed by microcontroller. Depending on this information, PIC produces PWM signal for buck converter power switch and decides sequence of phase windings. PWM signal controls speed of motor.

Appropriate phase must be energized to drive motor. PIC decides which power switch must be energized according to position. Next phase windings will energized with position data. Reference current level is used for limitation of maximum current of windings. Input values of PIC are motor position (x) and current value.

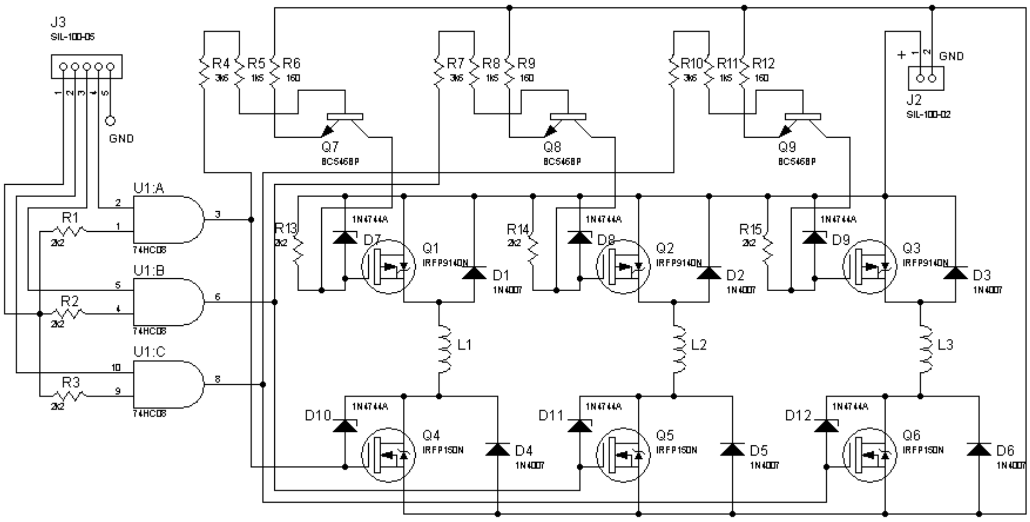

Fig. 4. Circuit of LSRM converter.

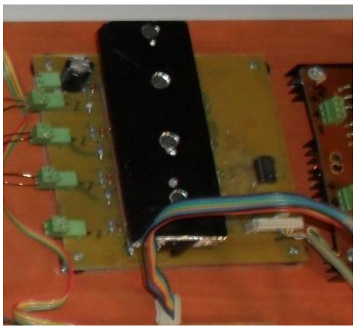

Fig. 5. The photo of LSRM Converter.

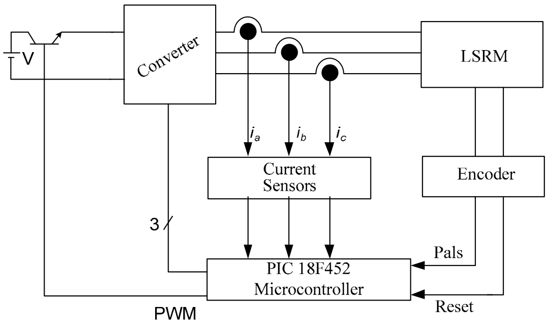

Fig. 6. Control block diagram of LSRM.

VI. Sensing Current Value

LSRM phase currents are measured as an analog value produced by LEM brand LA 55-P model. Analog value was increased microcontroller level (0-5V) by op-amps. For every phase current measured was used one current sensor. Fig. 7 shows current measurement circuit of one phase.

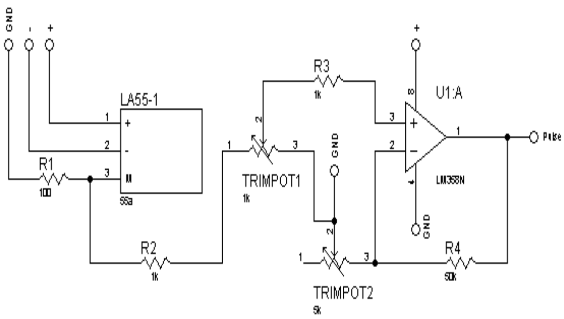

Fig. 7. Circuit of current sensor for one phase

Outputs of current sensors were connected analog input pin of PIC. This analog value was converted to 10 bit digital value and phase current was limited reference value. The views of current sensors are shown in Fig. 8.

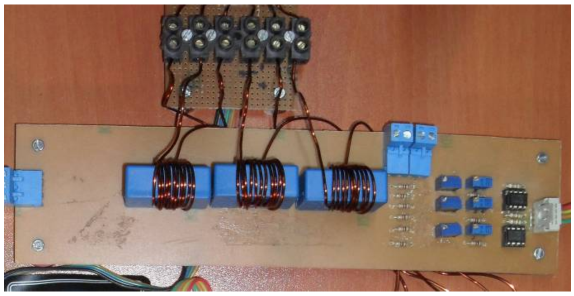

Fig. 8. View of current sensors circuit.

VII. Sensing Position Data

Linear incremental sensor was used for sensing motor position. It produces square wave pulse per 62.5 μm and also one reset signal per 0.5 mm. Pulses was sensed microcontroller's capture pin (high speed counter). Reset pulse was sensed external interrupt pin with high priority. Thus failure of sensed position was reset per 0,5 mm.

VIII. Microcontroller Circuit

PIC 18F452 microcontroller which has 32kb memory was used for control system. Motor speed was calculated with pulses which input from position sensor. This value was used for generating PWM signal that was generated from RC2 pin of PIC and send to MOSFET gate. Fig. 9 shows controller circuit scheme.

Linear incremental sensor generates 3 different signals that are named A, B and Z. A signal has 90 degrees difference than B signal and Z signal is reset pulse. B and A pulses were counted high speed capture of PIC. Thus, motor speed could calculate sensitively. Besides, PIC utilized working of system at desired values with sensing currents and position. Only current of energized phase winding was measured for fast working of system. In Fig. 10, view of controller circuit and in Fig. 11, view of whole driver and controller are shown. LSRM and driver are shown in Fig.12.

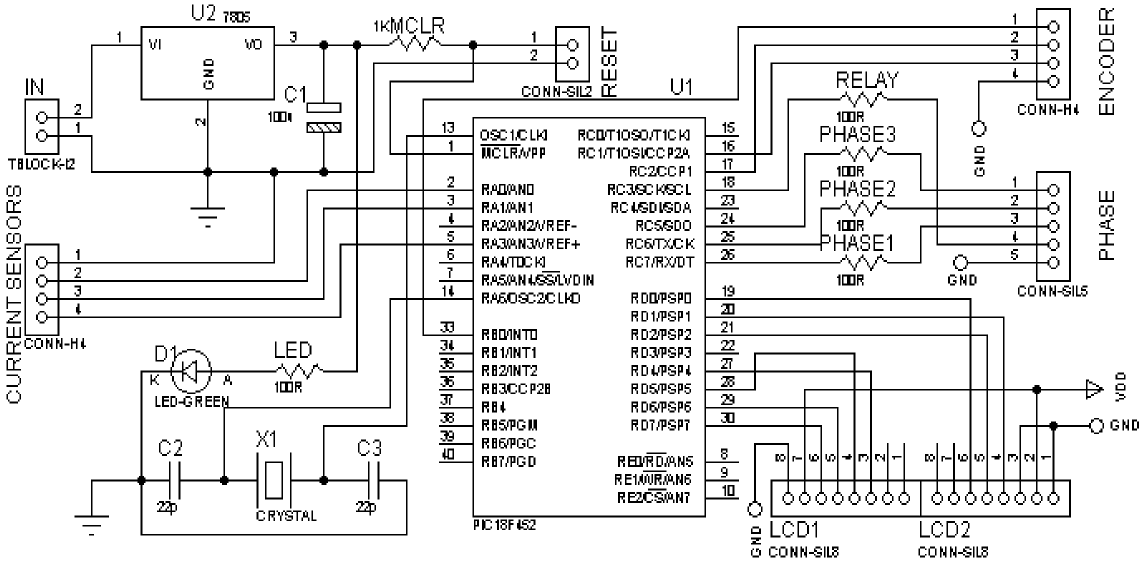

Fig. 9. Microcontroller circuit scheme.

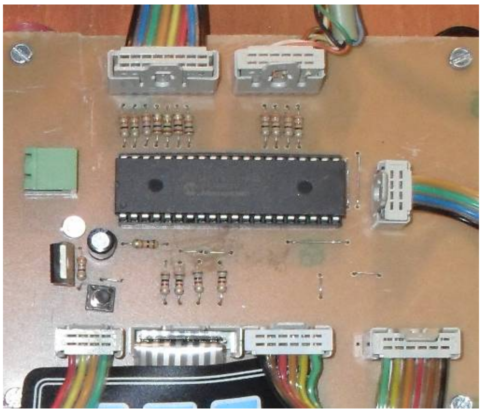

Fig. 10. View of controller circuit.

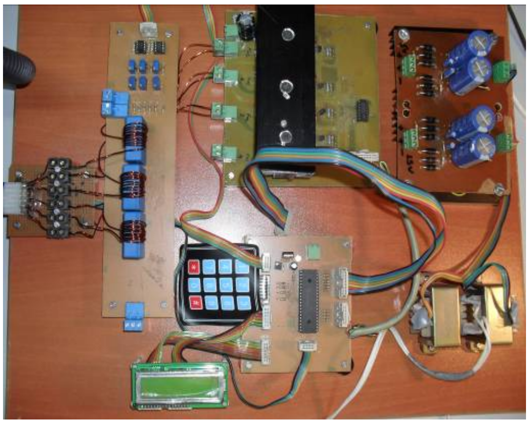

Fig. 11. View of LSRM driver.

The switching zones of LSRM are given (in Table I) and switching zones of phase currents and strategies are determined according to the motor's translator position. LSRMs'switching currents are obtained by simulation study are given in Fig. 12. 3 phase currents in simulation of LSRM.. In Fig. 13 scope view of LSRMs' switching currents are derived by experimental result. As a result of the designed LSRM is suitable short distance working such as automatic doors and don't need additional equipment for linear motion. It was realized that manufacturing of LSRM is very simple cause of that mechanical structure.

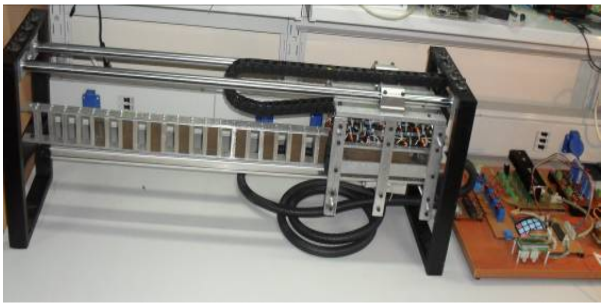

Fig. 12. LSRM and driver.

TABLE I: THE SWITCHING ZONES OF LSRM

Switching Zone	Phase A	Phase B	Phase C
0.00- 10.75	0	1	0
10.75- 19.00	0	1	1
19.00- 32.00	0	0	1
32.00- 40.25	1	0	1
40.25- 53.75	1	0	0
53.75- 61.75	1	1	0
61.75- 64.00	0	1	0

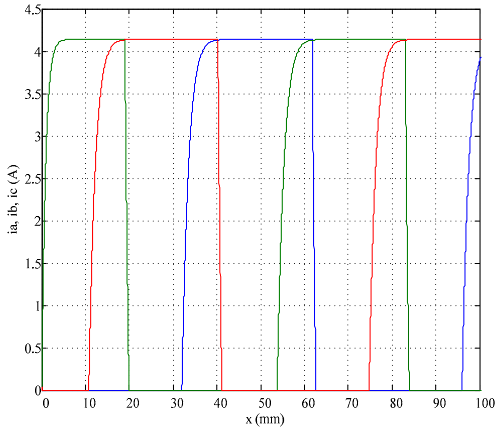

Fig. 13. LSRMs' switching currents

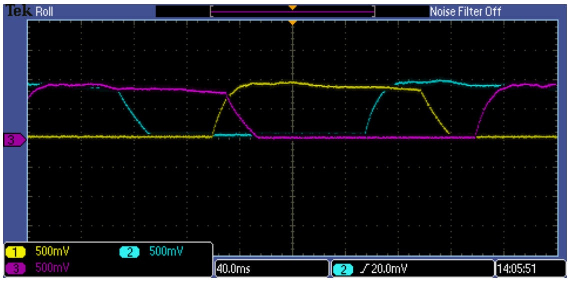

Fig. 14. Scope view of LSRMs' switching currents

IX. CONCLUSION

In this study, a driver has been designed for Linear Switched Reluctance Motor (LSRM) with 6/4 poles, 3 phases, 250W. LSRM controlled by PIC 18F452 microcontroller was used to drive automatic door. Motor was controlled more accurate with linear incremental encoder by sensing acceleration and movement direction of door.

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