International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-5, Issue-4, April 2018

An Electromagnetic Fixed-Wing UAV Launch System Based on Long Primary Double Side Linear Induction Motor

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***Abstract*— This paper describes the basic design and simulation using ANSYS Maxwell of double side long primary linear induction motor for fix wing Unmanned Aerial Vehicle (UAV). Choices of the basic structure and dimensions are presented and the motor has been designed with an emphasis on easy assembly, high thrust, high efficiency and high power factor. The results of the simulation on ANSYS Maxwell software will be revealed and discussed. In addition, the advantages of the linear induction motor are lower losses, simple control and simpler cooling.**

***Index Terms*— Fixe-wing UAV, Linear Induction Motor, Electromagnetic Launch System, ANSYS Maxwell.**

I. INTRODUCTION

In recent decades, **U**nmanned **A**erial **V**ehicle (**UAV**) have been employed in many applications in human life, Fixed-wing UAVs are used in several applications from agriculture to search and rescue. The take-off velocity, path and thrust are the most important features. Further on, the launch and recovery systems are the most difficult stage, and several systems of launching devices for UAV have been developed such as Pneumatic, Hydraulic, Bungee, Kinetic Energy and Electromagnetic launch system [1]. The Phoenix was fairly typical combat surveillance UAV and had a twin-boom UAV with a surveillance pod. It is a catapulted aircraft, with the propeller in the front.

Linear motor is a device that produces linear motion with using any mechanical transmission to convert from rotary motion to linear motion. Among different linear motors, short secondary linear induction motors have been used in electromagnetic aircraft launch system due to their high trust, simple structure, reduction in mechanical losses, controllability, good performance and low cost. All these merita make it an attractive motor [3].

The secondary of long primary double side LIM is made on lightweight conductive sheets (aluminum or copper block) which have the advantages of large payload and without power supply to the secondary. Therefore, it is suitable for launch UAV with high speed and large thrust [4]. Fig. 1 shows an example of Long Primary Double Side Linear Induction Motor (LP-DSLIM).

In this paper, based on the Phoenix UAV requirement the LP-DSLIM the motor has been designed. In this motor, the stator is semi-closed slot with one side and has an armature and a field system, except that in the linear motor the armature is stationary and the field is

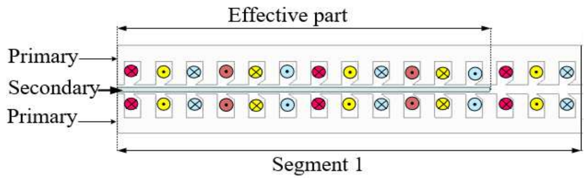

Fig.1 Basic segment structure of LP-DSLIM

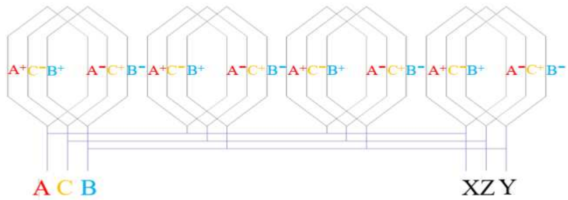

Fig.2 Single layer winding distributions

Moving. The single layer windings is chosen to increase flux density and the distribution armature windings ($A^+, C^-, B^+, A^-, C^+, B^-$) with $120°$ electric degree are shifted [6], as shown in Fig.2. The structure can save an amount of copper used in windings, reduce the flux leakage and electromagnetic interference to the outside of the motor [5]. In addition, the slip, air gap, mover thickness and the slot opening are optimized with 0.049, 6 mm,6 mm and 11 mm respectively to achieve the high force (MMF), efficiency and power factor.

Paper is organized as follows. Section 2 presents the Phoenix UAV take-off requirements. Section 3 discusses the basic design structure of LP-DSLIM. The optimal analysis and simulation results are presented in section 4. Finally, some conclusions are draw in section 5.

II. THE PHOENIX UAV REQUIREMENTS

The phoenix was the third generation of UAV in British Army service; it is combat surveillance UAV and mostly made of Kevlar and other plastic. In the operational application of UAV, the launch and recovery phases are often the most difficult stage. It is being launched from launch-rail mounted on the back of truck and have to be launched from distance of less than 9 meters. The UAV take-off requirements are shown in Table 1.

Table □ **I.** List of UAV take-off requirement

The Phoenix	Values
Mass	$180(kg)$
Wingspan	$5.6m$
Take-off Speed	$35(m/s)$
Acceleration	$78.5(m/s^2)$

Based on the above detail in table I, the launched requirements are:

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1) Force:

With using a formula of $F = ma$, a is displacement acceleration and m is the mass, $F = 14\ KN$, the actual force should be increased 50% by the effect of friction and other features $F = 21\ KN$.

III. Design Structure

In the design of LP-DSLIM launch system, efficiency and trust capability should be primary design considerations that are in the domain of the motor itself. Therefore, the design goal is to get the best efficiency possible, and that will optimize several parameters such as slip, air gap, mover thickness and slot opening. Fig.3 shows the basic structure of LP-DSLIM. The basic structure and winding connection type of this LIM have been used for electromagnetic launch system in [7].

A. The optimal Slip

The difference between synchronous speed and the mover speed is commonly referred to as the slip of the mover. Slip is most commonly defied as

$$s = \frac{n_s - n}{n_s}$$

Where n_s is the synchronous speed, n is the mover speed .Fig.4 presents the optimal result of slip to achieve the highest trust and efficiency, Table II shows the performance of the LP-DSLIM when the slip ratio change from 0.04 to 0.08, it can been see that the thrust, efficiency and power increase when the slip reaches 0.049, after which they decrease. Therefore, s=0.049 is the optimal slip to get the fore requirement.

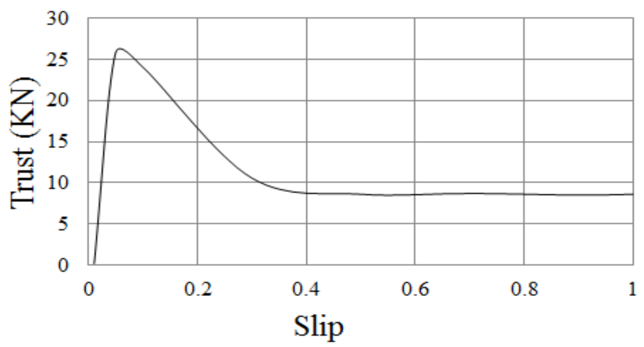

Fig.4 Thrust Force of Motor versus different slip ratio

TABLE II
THE PERFOMANCE CHANGING WITH THE SLIP RATIO

Slip Ratio	0.02	0.04	**0.049**	0.06	0.08
Thrust (KN)	15.16	25.24	**27.59**	27.25	25.72
Efficiency (%)	81.63	85.87	**85.97**	84.8	82.62
Power factor	0.205	0.324	**0.355**	0.352	0.342

B. The optimal Air Gap

The gap region is constant; it is bounded on either side by stator surfaces. In order to decrease the Total Harmonic Distortion (THD) and achieve the force requirement for launch motor the air gap is optimized. Table III shows the performance of the LP-DSLIM when the air gap parameter changes from 4mm to 8mm, and the thrust, efficiency and power factor decrease when the air gap increases, g= 6mm is the optimal air gap to achieve the force requirement and lowest THD.

TABLE III
THE PERFOMANCE CHANGING WITH THE AIR GAP

Air Gap (mm)	2	3	4	5	**6**
Trust (KN)	37.84	34.74	31.96	29.47	**27.22**
Efficiency (%)	88.14	87.58	87.7	86.41	**85.8**
Power factor	0.454	0.423	0.396	0.372	**0.35**

C. The optimal Mover Thickness

In order to increase the efficiency and the power factor of the motor and to satisfy the force requirement for launch system, the mover length and thickness should optimized, In this paper, the mover length is 4 poles pitch and thickness is optimized .Table IV shows the performance of the LP-DSLIM when the thickness change from 4mm to 8mm, it can been seen that the thrust , efficiency and power factor increase when the mover thickness increase unit get the highest value of $6mm$ after that decrease. The optimal dimension of the thickness is $6mm$ by iterative calculation.

TABLE IV
THE PERFOMANCE CHANGING WITH THE MOVER THICKNESS

Thickness(mm)	4	5	**6**	7	8
Trust (KN)	27.22	27.23	**27.79**	26.2	25
Efficiency (%)	85.63	85.7	**85.96**	85.55	85.21
Power factor	0.336	0.343	**0.357**	0.345	0.337

D. The optimal Slot Opening

The slot opening will affect the performance of the LP-DSLIM. Table V shows the performance of the motor when the slot opening change from 8mm to 14mm, where the slip ratio, air gap and mover thickness are optimized. It can been seen that the thrust , efficiency and power factor increase when the slot opening increase unit get the highest value of $11mm$ after that decrease. The optimal dimension of the slot opening is $11mm$ by iterative calculation.

TABLE V
THE PERFOMANCE CHANGING WITH THE SLOT OPENING

S.Opening(mm)	9	10	**11**	12	14
Trust (KN)	27.4	24.5	**27.52**	27.4	27.3
Efficiency (%)	85.89	84.15	**85.96**	85.95	85.93
Power factor	0.354	0.324	**0.358**	0.357	0.356

IV. Simulations and Results Design

A. Electromagnetic Performance

Based on the FEA results, the electromagnetic performance of the PL-DSLIM motor, with optimized parameters have been calculated and summarized in Table VI.

TABLE VI
LAUNCH PERFORMANCE OF LP-DSLIM

Items	Motor
Primary pole pitch, τp (mm)	35
Primary yoke height, *hpy* (mm)	27
Slot opening, *wso* (mm)	11
Secondary height, *hs* (mm)	6
Rated speed (m/s)	35
Frequency (Hz)	177.3
Current density (A/mm2)	12.47
Ipeak (A)	1500
F_avg (kN)	22
F_ripple (kN)	0.202
Copper loss (kW)	78
Iron loss (kW)	35
Eddy current loss (kW)	141
Efficiency (%)	**75.04**
Power factor	**0.301**

B. Flux Density Distribution

Fig.5 and Fig.6 shows the magnetic lines and flux density distributions of the motor at the rated current and rated speed condition respectively. It can be seen that the maximum value of the flux density is about 1.79T in the primary tooth tip and about 2.46T in the secondary segment tip in the LP-DSLIM motor. The air-gap magnetic flux density distributions of the motor are given in Fig.7 The positive and negative peak values of the air-gap flux density in the LP-DSLIM motor are about 0.81T and -0.83T, respectively, and it is similarly sinusoidal waveform.

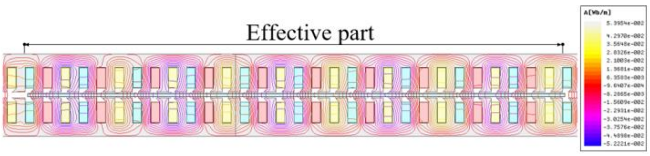

Fig.5 The flux line distributions of the LP-DSLIM at the rated current and speed.

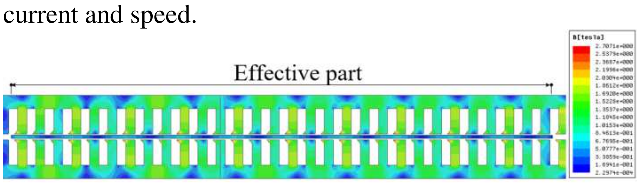

Fig.6 The flux density distributions of the LP-DSLIM at the rated current and speed.

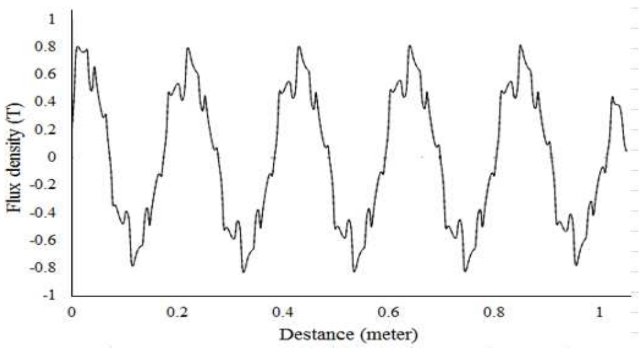

Fig.7 The air gap flux line distributions of the LP-DSLIM at the rated current and speed.

V. CONCLUSION

In this paper, a detailed design of the LP-DSLIM was performed and optimized several parameters of the motor to increase the trust force, efficiency and power factor. The main objective in this paper was to design a motor that achieved the UAV requirement. The Phoenix UAV was an example for payload of the motor to achieve the trust force requirement. It can conclude that the air gap and mover length play a very important role to decrease the THD and increase the trust force respectively. Another crucial design parameter is the mover thickness of the rotor, mover, which is aluminum. As the thickness of aluminum sheet increased trust also increases. To conclude with, in this project we achieved the Phoenix requirement to take off from the ground with speed of 35 m/s.

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