Design of Linear Switched Reluctance Motor with Segmental Mover for Electromagnetic Launching Applications


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Electromagnetic launching applications gain more and more attraction, which require high efficiency and force density. A new structure of Linear Switched Reluctance Motor (LSRM), Linear Switched Reluctance Motor with Segmental Mover (LSRMSM) has been studied to be a more significant alternative of electromagnetic launching applications. An overall design process of LSRMSM used in electromagnetic launching applications is proposed in this paper, which aims to achieve the requirements of launching application and enhance the efficiency both considering the dimensions of the LSRMSM and thermal analysis. The consequence of the process shows that the LSRMSM features excellent performance in the electromagnetic launching application as well as the higher efficiency and force density.

Index Terms—Electromagnetic Launching Applications, Linear Switched Reluctance Motor with Segmental Mover (LSRMSM), Design Process.

I. INTRODUCTION

Electromagnetic launching applications have been used in all aspects such as electromagnetic arms, which have received more and more attention [1]. Rather than chemical catapult devices, electromagnetic launching applications have low cost and risk. Thrust density is always the primary design concern for electromagnetic launching propulsion application since it determines the transportation efficiency [2]. Nowadays, a surge of interests in linear switched reluctance motor (LSRM) occurs due to the features of the body with simple structure, and the strong capability of the high fault tolerance and free maintenance of secondary. Moreover, Linear Switched Reluctance Motor (LSRM) produces direct force which needn’t convert torque to linear thrust, and has been proved to cost lower in the aspects of manufacturing and maintenance than Linear Synchronous Motor (LSM) and Permanent Magnet Linear Synchronous Motor (PMLSM) [3].

Linear Switched Reluctance Motor (LSRM) is an alternative for electromagnetic launching due to its advantages which are suitable to electromagnetic launching applications due to its high efficiency and low cost.

In this paper, a new structure of LSRM, Linear Switched Reluctance Motor with Segmental Mover (LSRMSM) is proposed, which features higher efficiency and force density than traditional LSRM.

II. DESIGN PROCEDURE AND MACHINE TOPOLOGY

The design of LSRMSM is gained by translating its specifications into equivalent LSRM specifications, which is also gained by translating its specifications into rotary switched reluctance motor. Then, the dimensions of rotary SRM are designed, from which the dimensions of LSRMSM is gained by inverse translation. The design procedure is based on (1)-(2).

\[
P = k_1 k_2 k_d B A_s D^2 L N_r
\]

\[
k_1 = \frac{\pi^2}{120}
\]

Where \( P \) is the power output, \( k_2 \) is aligned saturated inductance divided by unaligned inductance. \( k_d \) is motor efficiency, \( k_d \) is the duty cycle, \( B \) is flux density, \( A_s \) is specific electric loading, \( D \) is the diameter of rotary SRM, \( L \) is the stack length, \( N_r \) is the speed.

![Fig.1. 3D illustration of designed LSRMSM.](image)

The topology of LSRMSM is shown in Fig.1. The dimensions of designed LSRMSM are shown in TABLE I. The authors have considered other variables such as the current and number of turns. Fig.2 shows the control circuit of designed LSRMSM.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>MACHINE DESIGN PARAMETERS</th>
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</thead>
<tbody>
<tr>
<td>Definitions</td>
<td>Symbols</td>
</tr>
<tr>
<td>Number of phases</td>
<td>( q )</td>
</tr>
<tr>
<td>Number of turns</td>
<td>( T_{ph} )</td>
</tr>
<tr>
<td>Accelerate length</td>
<td>( x )</td>
</tr>
<tr>
<td>Maximum linear velocity</td>
<td>( v_{max} )</td>
</tr>
<tr>
<td>Instantaneous acceleration force</td>
<td>( F_a )</td>
</tr>
<tr>
<td>Stack length</td>
<td>( L )</td>
</tr>
<tr>
<td>Interval width between segments</td>
<td>( w_{ss} )</td>
</tr>
<tr>
<td>Mover tooth width</td>
<td>( w_a )</td>
</tr>
<tr>
<td>Stator tooth tip width</td>
<td>( w_e )</td>
</tr>
<tr>
<td>Mover tooth tip width</td>
<td>( w_{et} )</td>
</tr>
<tr>
<td>Stator slot width</td>
<td>( b_{sw} )</td>
</tr>
<tr>
<td>Stator narrow teeth</td>
<td>( w_{st} )</td>
</tr>
</tbody>
</table>
Several parameters of body dimension are subject to pre-setting constraints which are prepared for the design process. The following relationship which is to ensure the variables feasible can be satisfied in (3)-(6).

\[
\begin{align*}
\tau_s &= w_{sy} + w_{gs} \quad (3) \\
\tau_m &= b_{mm} + w_{sy1} \quad (4) \\
\tau_s &= b_{mm} + w_{sy2} \quad (5) \\
\tau_m &= w_{ms} + w_{sy2} \quad (6)
\end{align*}
\]

Fig. 2. Control circuit of designed LSRMSM.

III. CONCLUSION

This paper presents a procedure of design of the electromagnetic launching device. A new structure of LSRM is proposed with excellent performance. Compared with traditional LSRM, LSRMSM has proved to feature higher efficiency and force density. Fig.3 shows magnetic flux density of LSRMSM. Fig.4 illustrates the currents of 3 phases. The magnetostatic forces and commutation thrusts of the two motors are compared in Fig.5. The magnetostatic inductance of LSRMSM and LSRM is given in Fig.6. The FEA results shows that he LSRMSM features excellent performance in the electromagnetic launching application as well as the higher efficiency and force density.

Fig. 3. Magnetic flux density of designed LSRMSM.

Fig. 4. Phase current of designed LSRMSM.

Fig. 5. (a) Comparison of magnetostatic forces between the two motors. (b) Comparison of commutation thrusts between the two motors.

Fig. 6. Comparison of Inductance between LSRM and LSRMSM.

REFERENCES

