Characteristic Analysis of the Influence of Auxiliary Teeth and Notching on the Reduction of the Detent Force of a Permanent Magnet Linear Synchronous Machine

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Abstract

This study considered the reduction of the force ripple of a permanent magnet linear synchronous machine (PMLSM). The PMLSM has a relatively large magnetic air gap; thus, a slotted type of stator structure is generally employed. Furthermore, the detent force, which is caused by energy imbalances owing to the interaction between the teeth-slot structures and the permanent magnets (PMs), must be minimized for start-up operation.

Hereof, in this study, the addition of auxiliary teeth and teeth notching are employed to reduce the detent force. In particular, the influence of the auxiliary teeth and notching on the detent force was analyzed, and an experiment was performed for verification.

Analysis Model Precondition for the Detent Force of the PMLSM

Parameter Analysis Model

Performance of the Design and the Manufactured Model

Analysis of Detent Force

- Detent force formula

\[ f_t = \int B_{avg} l/dx \]

where: \( B_{avg} \) is the average magnetic flux density in the air gap, \( l \) is the length of the air gap, \( d \) is the distance between the stator teeth, and \( x \) is the distance from the slot center.

- Comparison of detent force results

FIG. 3 shows the performance force at rated output power conditions.

The value of the force in the generating mode is 100 N, but this result includes the detent force and the detent force value is 5 N.

Therefore, the maximum value of the electromagnetic (EM) force is 85 N.

As a result, the value of the detent force should not surpass a limit value of 5 N.

Analysis of the Basic Slot Model and Auxiliary Teeth

Parametric Analysis of the Basic Slot Model and Auxiliary Teeth

- Distribution of the flux line according to the auxiliary teeth.

- Manufactured auxiliary teeth and parametric analysis results of the auxiliary teeth for detent force reduction.

- Analysis of notching methods: (a) notching of teeth, (b) comparison of results of detent force.

TABLE II. Optimum Auxiliary Teeth Specifications.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Auxiliary teeth 1</th>
<th>Auxiliary teeth 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth width (mm)</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Tooth length (mm)</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Tooth thickness (mm)</td>
<td>4.8N</td>
<td>5.2N</td>
</tr>
</tbody>
</table>

Conclusion

- In this study, the detent force of a PMLSM was analyzed using FEA. In general, the detent force influenced the force ripple, especially from imbalanced magnetic energy in the air gap.

- The imbalanced magnetic energy is a result of the slotting effect of the stator structure. Therefore, the reduction of the detent force is important in the design of the machine. Two different models of auxiliary teeth and notching are used for parametric analysis.

- In addition, optimum point models are manufactured for experimental verification. The results reduce the detent force to 10% of the initial design model.