End Effect Reduction by Modification
Design of End Teeth for Linear Induction Motor

Abstract: - Using linear induction motors for magnetic trains has challenges in maintaining stability and safety, namely the emergence of holding forces. The force arises due to the magnetic flux interaction between the permanent magnet and the iron core. One source of resisting force is due to the dotted lines, which creates a finishing effect and generates vibration and noise from the system. Previous research has carried out several works, one of which is designing the shape of a gear at the end of a tooth with a convex curved shape in a linear synchronous motor which has succeeded in reducing the effect of the tip of the tooth. This study aims to determine the results of the effectiveness of calculations using MATLAB, which can produce much less resistance. This research uses descriptive research with a qualitative approach. In this study the calculations to redesign the shape of the dental arch at the end of the track were carried out by making a model with a parabolic approach. Plane dimensions X, Y, Z 660mm x 360mm x 360 mm. Magnetic density data were collected using Ansys software and 10 mm meshing, while the magnitude of the resistive force based on mathematical equations was carried out using MATLAB software. Investigation of the effect of curvature for the final effect value has been carried out using 6 models with different arcs. From the simulation, it is concluded that the sharpener for bow curvature gives the smallest resistance force value. The smallest result from the calculation $A=A_x+y''A_y$ gives the smallest detention force value. The smallest computation of $A=A_x+y''A_y$ with the sharpest curvature is a challenge to build and use for real activities.

Keywords: End Effect, End Teeth, Parabolic, Magnetic Density, Ansys, MATLAB.

1. INTRODUCTION

Recently, the single-sided linear induction motor (SLIM) has been the most appropriate choice for electric vehicles because of the wheel and touchless type. Its simplicity in constructions, capable of applying direct force as well as moving and braking, and many other advantages. Because of the limitations of track, no continuity of the magnetic field in these motors occur and inherent problems, which do not exist in the rotational-type motors [1]. One of the issues is longitudinal end effect which more complicated and has more influence on the performance of the motors since it will be increasing followed with primary speed [2]. Researchers has developed many ways to overcome the problems such as by using controller like adaptive which can make position more properly [3], another example is in using neural network controller for velocity controller [4] and by using Self-adjusting Fuzzy control system to decrease speed ripple [5]. Different way for reducing end effect is by balancing the effect with equivalent circuit [6], [7], [8], [9], [10], [11], [12]. and by adding auxiliary...
teeth [13], [14], [15], [16], [17], which still has drawback on trust force. Another way for similar purposes is by chamfering few of end teeth [exit end effect] which has been able to lower the end effect. In this research present a way to minimize the end effect by modifying chamfering end teeth which previous works has shown fine result on altering the end teeth [16]. Using the same dimension and by redesign the end teeth with concave curvature shape for inactive primary SLIM effectively lowering detent force from end teeth. Data for flux magnetic parameter are calculate using Ansys R19 and value of detent force is counted with parabolic approach by Matlab19.

**End Teeth Design Model**

End effect for linear motor happened because, the final teeth occurs due to the limited primary length resulting in changes in flux flow in the air gap and the spread of the current which is not homogeneous. And the end effect, can be analogized as the superposition of two waves at the beginning and end of lines [18]. End effect in exit end has more effect for the performance of the system because of dolphin phenomena. Single sided linear inductions motor with no moving primary is use in this works because it’s simple and more widely use as seen in figure 1, for design and dimension of end teeth with curvature of concave shape seen in figure 2 and figure 3.

![Figure 1. No moving primary SLIM](image1)

![Figure 2. Dimensions of the end teeth](image2)

![Figure 3. Curvature end teeth](image3)
For simulation purposes the dimension of end teeth is 66 mm wide and 36 mm high with variety of concave curvature. To increase the accuracy of the model, designing arc for each model by using numerical method with parabolic approach and material parameters in table 1

2. Research Methodology

### Table 1. Material Parameters

<table>
<thead>
<tr>
<th>No</th>
<th>Material</th>
<th>symbol</th>
<th>value</th>
<th>applied parameters</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Magnetic field</td>
<td>Bx,By</td>
<td>Ansys</td>
<td>Ansys</td>
<td>miliTesla</td>
</tr>
<tr>
<td>2</td>
<td>Air permeability</td>
<td>μ₀</td>
<td>4π×10⁻⁷</td>
<td>4π×10⁻⁷</td>
<td>Henry/meter</td>
</tr>
<tr>
<td>3</td>
<td>Permeability of materials</td>
<td>μᵣ</td>
<td>1000–5000</td>
<td>2000</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Magnetic field strength</td>
<td>H</td>
<td>936-1114</td>
<td>1000</td>
<td>kAmpere/m</td>
</tr>
<tr>
<td>5</td>
<td>Current Density</td>
<td>Je</td>
<td>0.4</td>
<td>0.4</td>
<td>miliAmpere/mm²</td>
</tr>
<tr>
<td>6</td>
<td>Deten Force</td>
<td>F</td>
<td>Output</td>
<td>output</td>
<td>miliNewton</td>
</tr>
</tbody>
</table>

**Parabolic Approach.**

Parabolic is use for designing the arch for each of the models. The surface of the parabolic plane with a peak (66.1) and is open upwards and passes through the coordinates (0.37) with several curvature models, the curvature parameter is a factor of $a$, then the parabolic equation model which is a quadratic function is expressed in equation 2.1

$$y=a(x-66)^2+1 \quad (2.1)$$

Parabola passes the coordinates (0.37), and the score of $a=0.008585$ then the equation of the parabola which is parallel to the z axis becomes

$$y=0.008585(x-66)^2 + 1$$

$$y=0.008585x^2-1.1121x+37 \quad (2.2)$$

So the surface plane equation is $\Phi(x, y)$ and is expressed as an implicit function $\Phi(x,y)=0.008585x^2-1.1121x+37-y=0$

For simulation purposes six parabolas is taken with three points (0.37), (33, $y_T$) and (66.1) with variation value of $y_T$, and the general form of the parabola equation used is:

$$y = a_1x^2 + b_1x + c_1 \quad (2.3)$$

$$y = ax^2 - 132ax + 66^2a + 1 \quad (2.4)$$

For simulation six parabolas was taken with variety curvature for several value of $y_T$ which is changed through three points (0.37), (33, $y_T$) and (66.1).
37 = a_0 x^2 + b_0 x + c_i \quad (2.5)
9.65 = a_i x^2 + b_i x + 37 \quad (2.6)
1 = a_i x + b_i x + 37 \quad (2.7)

Hence

\[ a = 0.0085858586 \quad \text{and} \quad b = -1.112121, \]

The formation of a parabolic model is made by changing the distance between the \( y_T \) values as \( y_T + 0.05 \) so that the parabolic equations with the coefficients \( a_i, b_i \), and \( c_i \) as seen on table 1.

(a) \( y_1 = 0.008585x^2 - 1.1121x + 37 \)
(b) \( y_2 = 0.008631x^2 - 1.1151x + 37 \)
(c) \( y_3 = 0.008677x^2 - 1.1181x + 37 \)
(d) \( y_4 = 0.008723x^2 - 1.1212x + 37 \)
(e) \( y_5 = 0.008769x^2 - 1.1242x + 37 \)
In order to find out the trend of the score for each model, simulation was made by using six parabola models. Mathematical Model for Detent Force Detent force because of end effect generated by two sources, they are entry end effect and exit end effect. which is depicted in the equation 2.8

$$A_y(x,t) = A_1(x,t) + A_{entry}(x,t) + A_{exit}(x,t)$$  \hspace{1cm} (2.8)

with :

$$A_1(x,t) = A_s \cos(\omega t - kx + \delta s)$$

$$A_{entry}(x,t) = A_1 e^{-\gamma / a_1} \cos \omega t$$

$$A_{exit}(x,t) = A_2 e^{-\gamma / a_1} \cos \omega t$$

$$F_x = \frac{1}{2} Re \left[ \iiint J_e A_y * ds \right]$$

$$F = \frac{1}{2} Re \iiint (J_e \times B) * ds$$

Here, $J_e$: current density, $A_y$: magnetic flux density, $ds$: differential surface element.

$$F=\frac{1}{2}Re\iiint J_e[(2a_i x + b_i)A_y + A_x]dxdz$$  \hspace{1cm} (2.9)

Discrete form:

$$F=\frac{1}{2}Re\sum_{x=0}^{360} \sum_{z=0}^{660} J_e[A_x + (2a_i x + b_i)A_y] \Delta x \Delta z$$  \hspace{1cm} (2.10)

Results and discussion

The detent force is influenced by the magnetic field intensity $A_x$, $A_y$ and the surface curvature function is used, namely the gradient of the surface function.

Simulation result in figure 6, shows that for model y1 with the sharpest curvature has the smallest value of detent force compare to the others. The opposite things happened for model y6 which have the biggest value from of all model with less sharp of curvature. From the simulation, produces that the changing form is a component of the magnetic field that varies according to the function of the x and y distances, also The detent force $F$ is only affected by the magnetic field in the horizontal axis direction $A_x$. 
If $A = A_x + y'A_y$ close to zero or zero, resulting in detent force $F$, is close to zero or very small.

Further research with another approach has to conduct in order to find minimum value of detent force as well as ease of manufacture.

**Conclusion**

An investigation the effect of curvature for the value of end effect has been made by using 6 model with different arc. From the simulation come the conclusion that the sharper for arc curvature gives the smallest value of detent force. Smallest result from calculation of $A = A_x + y'A_y$ gives the smallest value of detent force. Smallest calculation of $A = A_x + y'A_y$ with sharpest curvature has its challenges to build and use for real activity.

**References**


