Modification of the permanent magnet linear synchronous motor's shaft for fixing ring shape permanent magnet

N. A. Mohd Nasir [1, 2, *], F. A. Abdul Shukor [1, 2], R. N. F. Raja Othman [1, 2]

[1)] Electric Machine Design, Centre for Robotics and Industrial Automation (CeRIA), Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2)] Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[*]Corresponding e-mail: m011620008@student.utem.edu.my

Keywords: ferromagnetic; PMLSM

ABSTRACT –The fabricated permanent magnet linear synchronous motor (PMLSM) faced problem during the process of attaching the permanent magnet (PM) to a shaft. The shaft was made from a non-ferromagnetic material. The non-ferromagnetic shaft was modified by replacing the non-ferromagnetic material with a hollow ferromagnetic material to solve the problem. Considering the existence of flux leakage in ferromagnetic material, the models of PMLSM with different combinations of the ferromagnetic and non-ferromagnetic shaft has been modeled. The simulation results show that the model with shaft ratio 3:3 (mm) produced the highest average thrust which is 186N.

1. INTRODUCTION

The permanent magnet linear synchronous motor (PMLSM) has been designed where the performances of the PMLSM has been discussed in [1,2]. Based on the performances analysis, the best model with the optimum performances was chosen for fabrication. The model chosen is l_t=1.5mm, h_t=1mm where this model produced average thrust, F_{ave} of 176N.

2. BASIC PRINCIPLE OF THE PMLSM

2.1 Basic Structure of the PMLSM

The PMLSM consists of six stator slot and the Halbach magnetization array of PM on its mover as shown in Figure 1. The mover of the shaft consists of shaft and PM where the shaft made of non-ferromagnetic material and the PM is neodymium iron boron (NdFeB). Meanwhile, the stator yoke is made of ferromagnetic material with grade SS400 stainless steel.

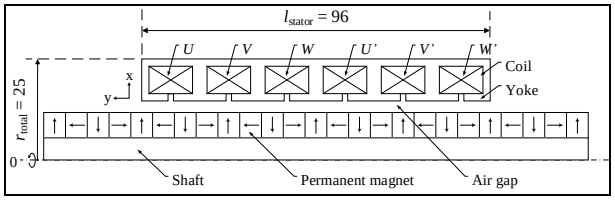

Figure 1 PMLSM basic structure (unit: mm).

2.2 Fabrication of the PMLSM

Based on the performances comparison of the PMLSM as discussed in [1,2], the final model, l_t=1.5mm, h_t=1mm was chosen for fabrication. Each part of fabricated PMLSM is then needed to be assembled as one complete structure. However, during the process of mounting PM to the shaft, some of the mounted PMs do not stick to the shaft as shown in Figure 2.

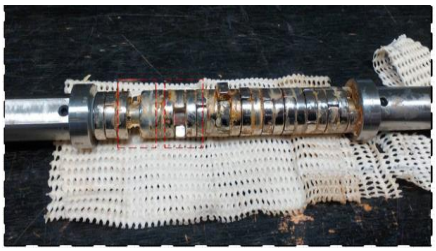

Figure 2 Mounted PM on the shaft.

In order to overcome this problem, the modification is needed to be done to the shaft. Due to the fact that magnets strongly attract ferromagnetic materials, it is decided to replace the non-ferromagnetic shaft with a hollow ferromagnetic shaft.

2.3 Ferromagnetic Shaft

Before the modification of the shaft can proceed, the changes towards the performances of the PMLSM needed to be considered. This is because, the ferromagnetic shaft produces leakage flux. Leakage flux is a condition where the magnetic flux does not flow in its original intended path [3] and does not contribute to the thrust development. This condition can degrade the performances of the PMLSM.

3. MODIFICATION OF THE SHAFT

The proposed modification of the shaft is conducted within fixed parameters of the PMLSM. The shaft radius r_{shaft} was maintained at 6mm. The shaft was modeled to have both a combination of ferromagnetic and non-ferromagnetic material in order to study the effect of leakage flux towards the thrust of PMLSM.

3.1 Combination of Shaft Material

Leakage flux can happen when the ferromagnetic material of the shaft allowed the magnetic flux of the PM pass through it. Therefore, the size of the ferromagnetic material of the shaft needs to be

optimized by combining the ferromagnetic material with a non-ferromagnetic material. Figure 3 shows the structure of the PMLSM with the combination shaft.

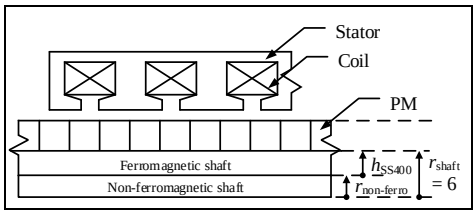

Figure 3 PMLSM with combination shaft (unit:mm).

The height of the ferromagnetic shaft, h_{SS400} to the radius of non-ferromagnetic shaft, $r_{non\text{-}ferro}$ combination are listed in Table 1. The models designed was then simulated to evaluate the performance of the thrust, F.

Table 1 Combination of shaft material.

No.	Ratio of $h_{SS400}/r_{non\text{-}ferro}$ (mm)
1	1:5
2	2:4
3	3:3
4	4:2
5	5:1
6	6(fully ferromagnetic)

4. PMLSM WITH FERROMAGNETIC SHAFT

The PMLSM with ferromagnetic shaft was modeled and simulated by using FEM software. The results of thrust obtained was compared to identified the optimum model. The shaft of the chosen model was then fabricated to replace the previous non-ferromagnetic shaft.

4.1 Average Thrust, F_{ave} Characteristics

Table 2 and Figure 4 show the average thrust, F_{ave} of the PMLSM for different ratio of shaft thickness. Based on Table 1, it shows that the average thrust, F_{ave} of model with ratio of $h_{SS400}/r_{non\text{-}ferro}$ equal to 3:3 produces the highest average thrust, F_{ave} which is 186N.

Table 2 Average thrust of modified shafts

Ratio of $h_{SS400}/r_{non\text{-}ferro}$ (mm)	Average thrust, F_{ave} (N)
1:5	182
2:4	183
3:3	186
4:2	185
5:1	185
6	185

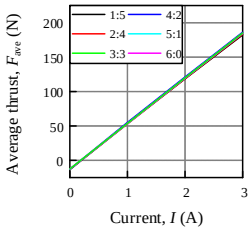

Figure 4 Average thrust, F_{ave} characteristics (3A).

4.2 Assembling PMLSM

Based on the finding, the the shaft with the ratio of $h_{SS400}/r_{non\text{-}ferro}$ equal to 3:3 was chosen for fabrication. The PM then mounted on the new shaft and the result is shown in Figure 5. Technically, the PM was successfully attached to the ferromagnetic shaft. Hence, the assembling of the PMLSM was continued with the ferromagnetic shaft as the mover.

Figure 5 PM mounted on the modified shaft.

5. CONCLUSION

In conclusion, the shaft with ratio of $h_{SS400}/r_{non\text{-}ferro}$ equal to 3:3 was chosen for fabrication to replace the non-ferromagnetic shaft. This is based on the finding that this model produced the highest average thrust compared to the other model. The average thrust produced by the model is 186N. Therefore, for the fabrication, it is decided to choose the model with half ferromagnetic, half non-ferromagnetic material as the shaft.

ACKNOWLEDGEMENT

Authors are grateful to Universiti Teknikal Malaysia Melaka for the financial support through PJP/2017/FKE/HI12/S01537.

REFERENCES

[1] Mohd Nasir, N.A., Abdul Shukor, F.A., Raja Othman, R. N. F. K., Wakiwaka, H., Tashiro, K. and Nirei, M. (2018). Design of the permanent magnet linear synchronous motor for high thrust and low cogging force performance. *Progress in Electromagnetics Research M* (PIER M) *63*, 83-92.

[2] Mohd Nasir, N. A., Abdul Shukor, F. A., Raja Othman, R. N. F. K., Wakiwaka, H. and Tashiro, K. (2017), Design of permanent magnet linear synchronous motor stator to improve magnetic flux density profile toward high thrust density performance. *Modeling, Design and Simulation of Systems, AsiaSim 2017, Communications in Computer and Information Science, Springer, Singapore,* 443-454.

[3] Hwang C.C., Cho, Y.H. (2001), Effects of leakage flux on magnetic fields of interior permanent magnet synchronous motors. *IEEE Transactions on Magnetics 37(4)*, 3021-3024.