Modeling Energy Losses in a Linear Magnetic Drive System

Ming-Jen Chen and Dr. Ilya Avdeev
Advanced Manufacturing and Design Lab, Department of Mechanical Engineering

Motivation
Energy efficiency is an important consideration for most manufacturing processes. Energy costs rise every year, but more importantly, heat losses negatively impact performance of manufacturing lines. In some cases, heat losses become a limiting factor in design of such systems.

In this research, energy losses of a commercial linear magnetic drive system are investigated both experimentally and through finite element analysis modeling.

In this investigation, assumed material properties and boundary conditions, including the winding number of coils and input load were used for the simulations.

Introduction
The linear motor is a kind of machine that can convert electricity into a linear mechanical movement. It means the linear motor can be seen as a rotational motor which has an infinite diameter. The principle of how the linear motor works is the same as rotational motors. However, it has some advantages and disadvantages which cannot be found in rotational motors. For example, the structure of a linear motor is simple, and it is only composed of several coils and magnets. The characteristics make it easy to maintain. As a result, linear motors are widely used by manufacturing companies. However, every coin has two sides. Efficiency has always been an issue for linear motors. This is the reason why this project is focused on energy loss of the linear motor.

![Figure 1: Linear Motor Testbed](image)

Methods
It’s easy to get the thermal field by setting up an experiment, but it’s still hard to know the efficiency of the system. To have a better understanding of the linear motor, building a 3D numerical model of a system is significant for applying the finite element method (FEM)[3]. To fulfill the requirements of FEM, simplifying the numerical model is necessary. Both the numerical model and the simplified model are shown below:

![Figure 2: Numerical full and simplified models](image)

Three scenarios were set for the project as below:
1. The motor(magnets) is steady(without moving).
2. The motor is moving at 1.0 m/s.
3. The motor is moving at 1.5 m/s.
4. The motor is moving at 2.0 m/s.

Experimental Setup
Besides the numerical simulation, the experiment is essential to this project. Arduino Uno and LM35(thermal sensor) were used in the experiment for the purpose of getting the thermal distribution.[4] The experimental setup was shown below:

![Figure 3: Experimental Setup](image)

Results

![Figure 4: Magnetic Field](image)

![Figure 5: Core Heat Loss](image)

![Figure 6: Core Loss at Different Velocities](image)

![Figure 7: Measured Temperature Distribution of the Testbed](image)

Discussion
By conducting the numerical simulation, the core losses would be found with different velocities. It’s obvious that the core losses would increase with the velocities increasing.[5] By applying higher velocity to the linear motor, the manufacturing line could have higher productivity than lower velocity. However, being more productive means having higher energy losses. Therefore, assigning the proper commands to the linear motor by following the needs would be an important duty for the manufacturing line.

![Table](image)

Future Work
- Run experiments and FE analysis for various scenarios of payloads, accelerations, ambient conditions and material properties of the system.
- Build the Reduced-Order Model that can be a foundation of a digital twin numerical model.
- Design a Digital Twin for Real-Time heat loss monitoring and mitigation.

Literature cited
[3] [3] [3] [3]

Acknowledgments
This project is supported by the Connected Systems Institute Research Grand and by Rockwell Automation. The authors would like to thank Joe Zachara and Michael Cook for their help in developing a testbed for this project.

Contact Information:
Ming-Jen Chen
Email: mingjenchao@wisc.edu
Address: 1200 N Craner St, Milwaukee, WI 53211

Dr. Ilya Avdeev
Email: avdeev@uw.edu
Address: 1200 N Craner St, Milwaukee, WI 53211