Electrical Engineering Department

Linear Induction Motor

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Introduction

Motion control applications are commonplace in our technological world and they are becoming even more ubiquitous alongside our ever-increasingly automated lives. Linear actuators are a vital part of these applications and are used in applications such as robotics, prosthetics, or other mechatronic hardware. Almost any operation typically performed by hydraulics or pneumatics is an application for a linear induction motor.

The most common methods to achieve electric linear motion is with a lead screw or rack and pinion (R&P) drive; however, these all have drawbacks. The lead screw lacks speed and due to "screw whip" problems it is not recommended for long strokes. The R&P suffers in vertical applications and can have backlash issues. Both drives have a lot of mechanical components that require maintenance, experience wear and may be unsuitable in certain environments.

Linear induction motors offer a variety of advantages. They are brushless and don't require gears systems that could be damaged in dirty environments. They have few to no mechanical parts so there is little need for maintenance and repair. They also offer high speeds and high force. The drawbacks to linear induction motor is that they require a more complex controller and more magnetic hardware.

Our goal with our project was to create a scalable linear induction motor that has little force ripple along its travel and that we could accurately control the force throughout its travel. We accomplish this using a stationary array of coils and two permanent magnets.

Methodology

Concept

The coil array, diagram in figure 1, consists of six coils spaced 48 mm apart from each other in a straight line supported by a section of one inch PVC pipe. Each coil is over 1000 turns of 22 gauge wire. To separate the coils we used custom 3D printed ABS parts. Inside the PVC pipe there is a rod with two Neodymium magnets fastened on it, with poles opposing each other, 120 mm apart.

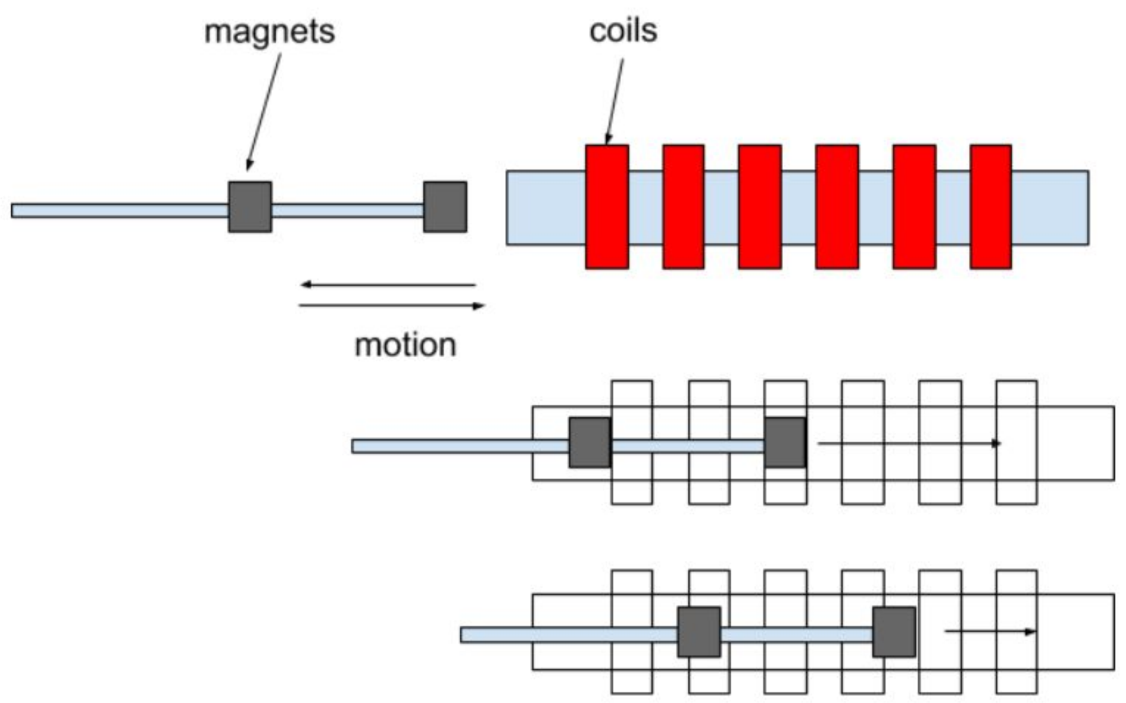

Figure 1, Cross section of the linear induction motor hardware

Methodology

Theory

To correctly space the coils and magnets we characterized the force versus distance of one coil and one magnet below in figure 2. Note this curve is shown with assumed commutation which produces the symmetry.

Using this curve we positioned the other coils and added a magnet so that the superposition of these with accurate current commutation would reduce the ripple inherent to our setup. This theoretical superposition is shown below in figure 3.

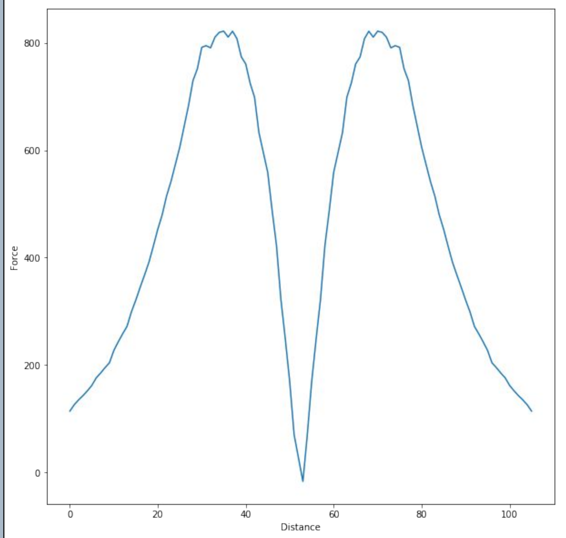

Figure 2, Force characteristics of one coil and one magnet

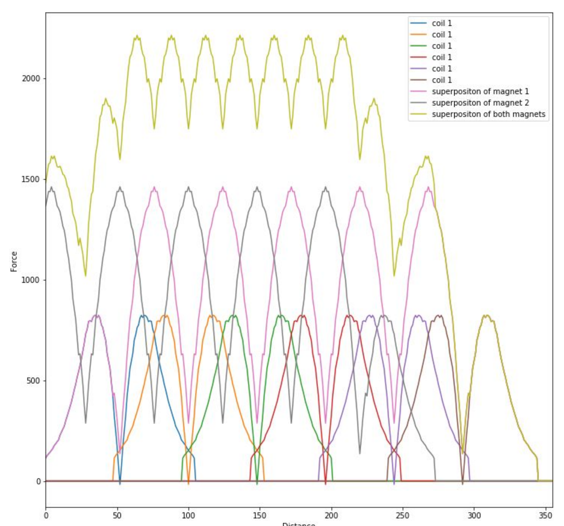

Figure 3, Theoretical force characteristics of six coils and two magnets

To further reduce the ripple we pulse width modulated (PWM) the current in the coils which has the effect of linearizing the peaks in the force curve as shown below in figure 4. However, one drawback is that this reduces our overall force.

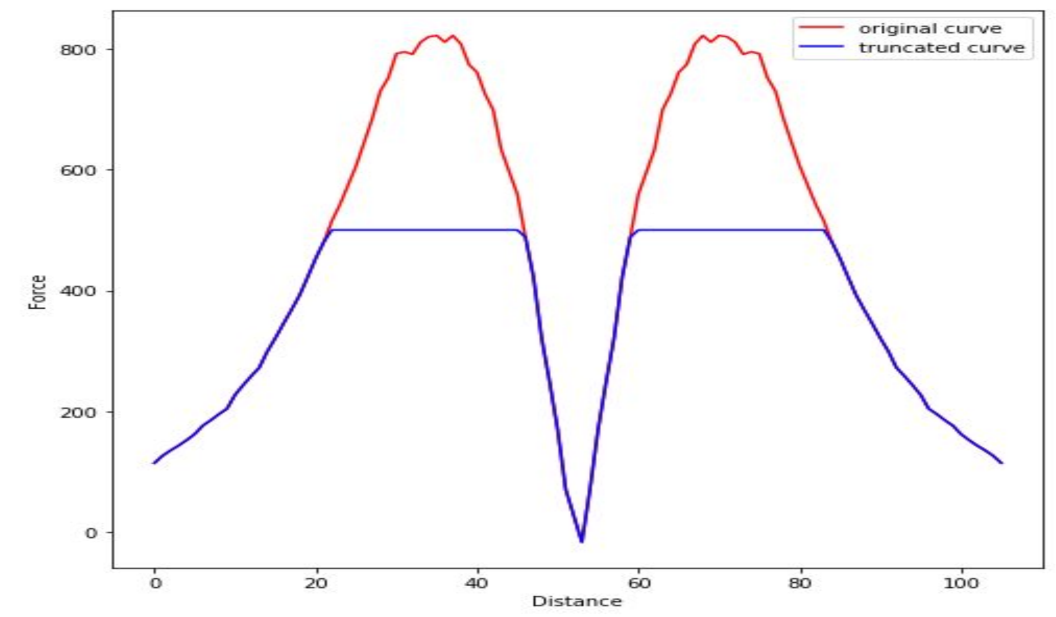

Figure 4, Theoretical force characteristics of one coil and one magnet with active PWM control

Implementation

We used the SAMD21 microcontroller (MCU) to determine magnet position, commutate and PWM the current to coils. To measure the absolute position we used a potentiometer (Pot) in a voltage divider setup. The Pot is connected to the magnetic rod in a rack and pinion system and the ADC on microcontroller reads the Pot and converts this to a relative distance.

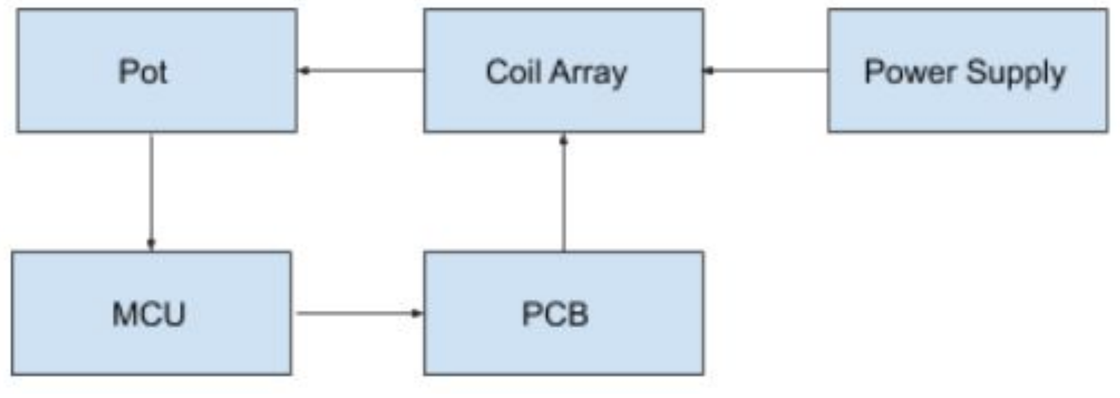

Figure 4, Overall system block diagram

Methodology

Moving From Left to Right							
Start of Stage (X)	End of Stage (X)	Coil 1	Coil 2	Coil 3	Coil 4	Coil 5	Coil 6
-P	0	1	1	-1	0	0	0
0	P/2	1	0	1	-1	0	0
P/2	P	-1	1	1	-1	0	0
P	3P/2	-1	1	0	1	-1	0
3P/2	2P	0	-1	1	1	-1	0
2P	5P/2	0	-1	1	0	1	-1
5P/2	3P	0	0	-1	1	1	-1
3P	7P/2	0	0	-1	1	0	1
7P/2	9P/2	0	0	0	-1	1	1

Figure 5, Sketch of required commutation pattern for one direction of travel

By knowing the magnet position we commutate the coils using the commutation table above in figure 5 and also actively control the PWM duty cycle. These signals go from the microcontroller to the PCB that contains our current supply circuits.

The PCB, or motor driver board, has six identical circuit blocks of H-bridge switches and current sensing components with low pass filters and decoupling capacitors. One single circuit block is displayed in figure 6. Also, the motor driver board includes the pot circuit and connectors. These circuits receive signals from the MCU and control output current to the coils. The power supplied to the board is from an external AC-DC 110 W 24V output power supply.

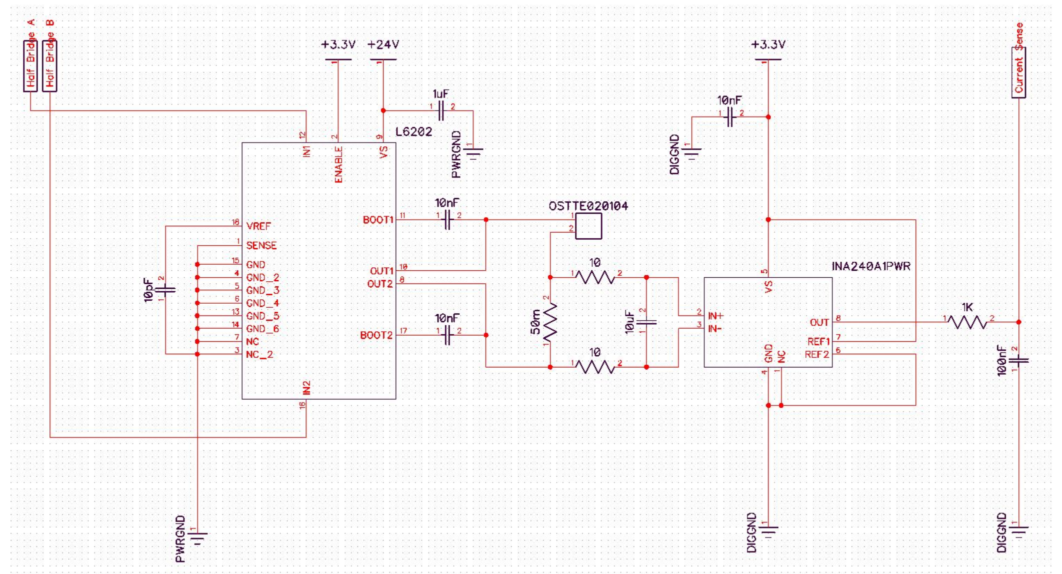

Figure 6, H-bridge current delivery circuit

Analysis and Results

After achieving the correct commutation and linearizing through PWM we recharacterized our motor's force vs distance. The results are shown below in figure 7 showing the raw data. The plot in figure 8 is showing the raw plot overlaid on a section of the theoretical superposition plot shown earlier. Note the raw linearized data is artificially shifted in the overlaid plot for visualization. However, note that this plot is masking one of the drawback of using PWM which is the lower overall force as mentioned earlier.

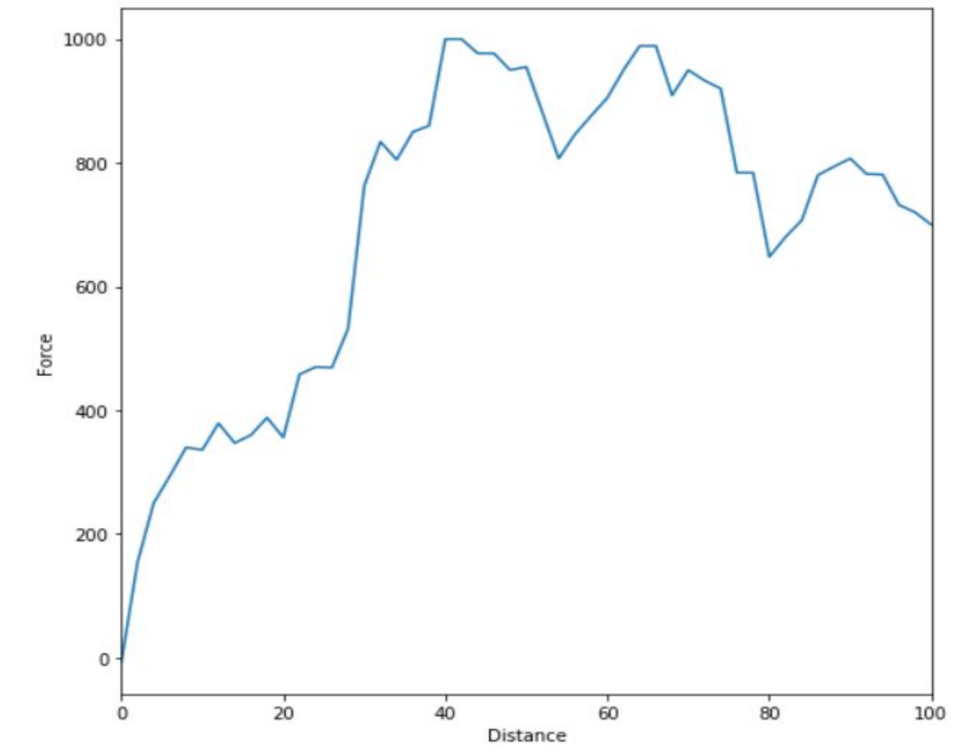

Figure 7, Actively controlled PWM force characterization of a section of the motor's stroke

Analysis and Results

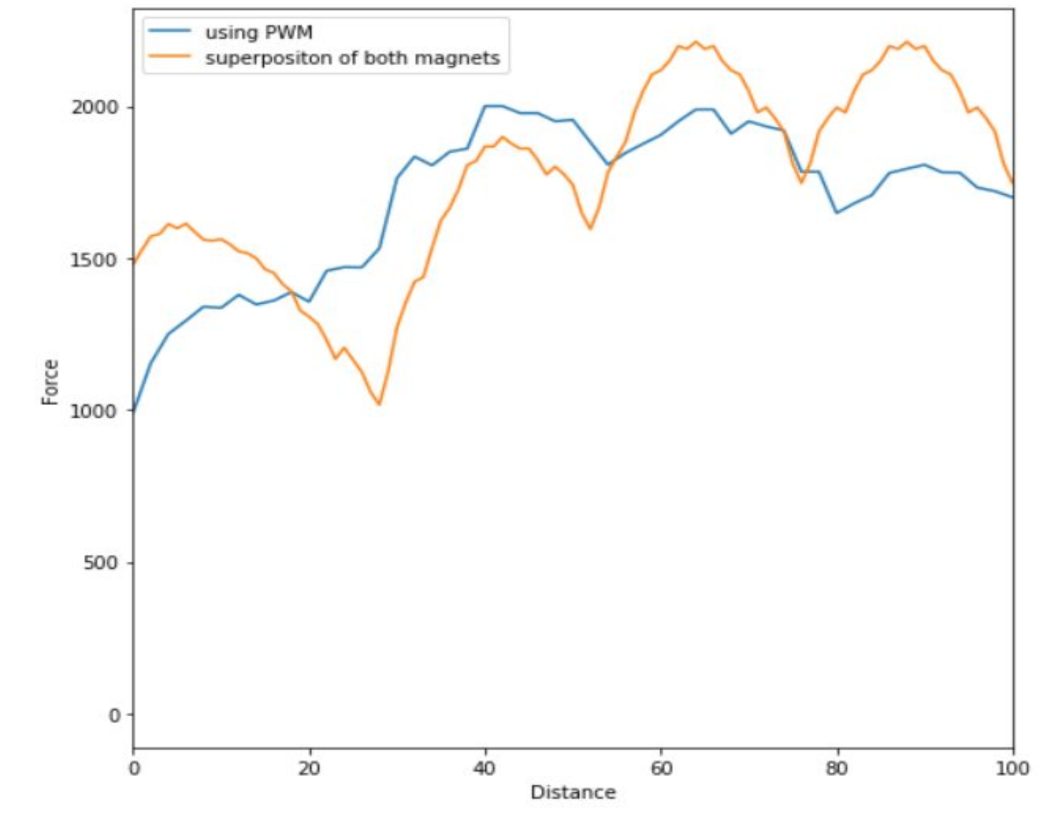

Figure 8, Actively controlled PWM force characterization compared to previous theoretically extrapolated plot with inert PWM control, note that the active PWM control plot is shifted to better compare the difference

Summary/Conclusions

After creating a six coil array with calculated coil spacing and a magnetic rod with two magnets also at calculated spacing we were able to achieve linear travel that had little ripple. To reduce the remaining ripple we recommend trying different coil/magnet. One possible configuration could add more magnets to fill any troughs with peaks. Yet another could be to reduce the length of the coils and magnet, thereby increasing the resolution of our system, however more coils and associated circuits would be necessary to achieve the same stroke. Another method would be to overlay the coil winding perhaps sinusoidally or in some other fashion. A possible benefit of overlaid coils is the elimination of multiple magnets.

Finally, adding the current feedback that is already included in our PCB could help increase the force of our motor by addressing the back EMF that naturally occur in electromagnetics.

Key References

[1] Microchip, "SAM D21 Family" Microcontroller Datasheet.

[2] STMicroelectronics, "DMOS FULL BRIDGE DRIVER" L6201 datasheet

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[3] Texas Instruments, "INA240 High- and Low-Side, Bidirectional, Zero-Drift, Current-Sense Amplifier With Enhanced PWM Rejection" INA240A1PWR datasheet, July 2016 [revised FEB. 2018].

Acknowledgements

Special thanks to our advisor professor Ping Hsu. His guidance and insight lead us to explore avenues we did not consider, and his experience helped us troubleshoot and solve challenges we encountered.

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