Manufacturing and Testing the Permanent Magnet Linear Motor with Two Structures

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Abstract

Controlled mechanical motion is vital for many useful applications in technology. For many of these applications, linear motors have advantages over traditional rotating motors. In this work, we have built a permanent magnet linear motor to test and measure energy efficiency. We find a maximum 30% total energy efficiency, and 79% energy transfer rate. In addition, a C shape support structure is added to the moving part in order to increase the moving accuracy. The test shows that, with the support structure, the fluctuation on vertical direction decreases significantly, but the friction of the system increases a bit.

Motivation

Linear motors have great performance in terms of accuracy, thrust force, and acceleration. They are widely used in applications that require linear motion, such as aircraft launching and CNC station.

Figure.1 displays how to imagine a linear motor. After the expansion, the rotator part becomes the mover, and the outer shell becomes the stator part.

As Figure.2 shows, the magnetic force equation $F = q\boldsymbol{v} \times \boldsymbol{B}$ says that , by sourcing current through the coil, a force would be generated by moving charges in the magnetic field.

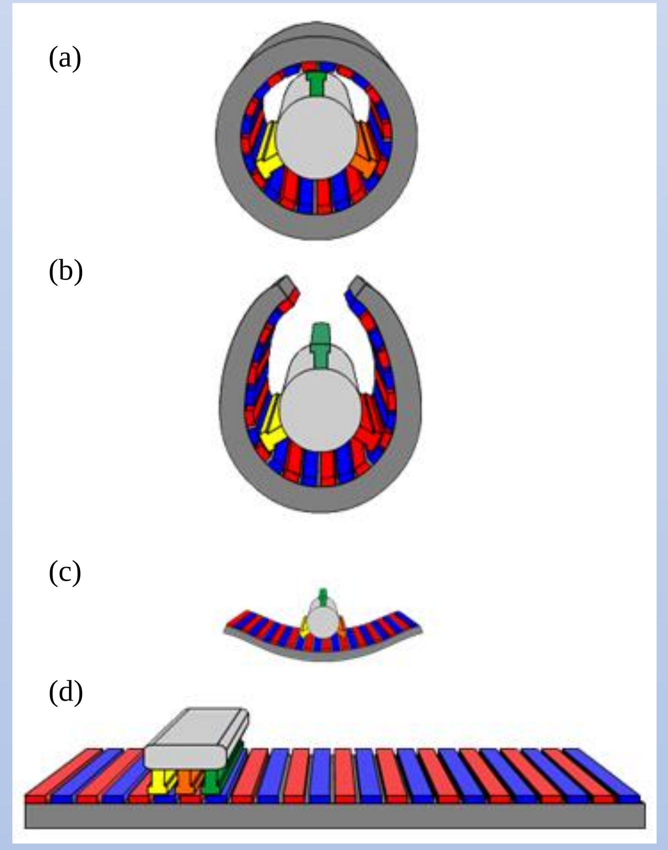

Figure.1: Diagram showing the process of a rotating motor expands to a linear motor. (a) a common structure of the rotating motor, (b) and (c) two transferring structures, (d) a practical structure of the linear motor. Image used with permission from Shcnibbi678.

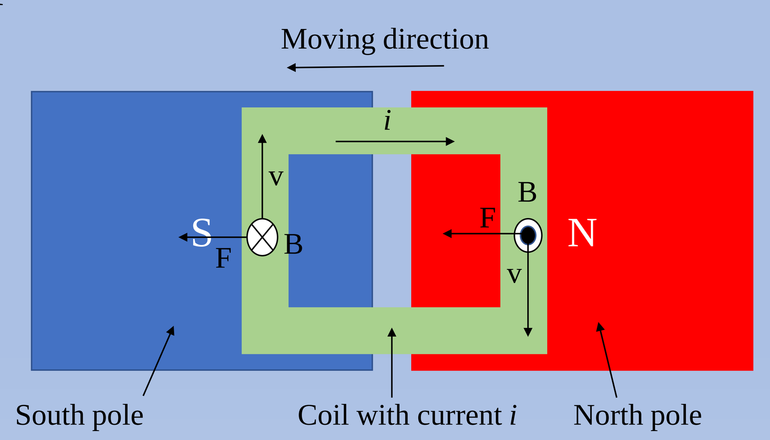

Figure.2: Diagram showing a basic part of a linear motor. Blue and red rectangles are south and north pole of permanent magnets. Green component is the coil of electromagnets. The current *i* in magnetic field generates force F as shown in the figure

Theory

Assuming the friction and thrust force is constant all the time. By varying the input voltage the acceleration should fit the equation:

$$Thrust\ force = Friction + acceleratrion \times mass$$

Furthermore, the efficiency of the system is given by equation:

$$\eta = \frac{kinetic\ energy\ of\ the\ mover}{total\ energy\ provided\ by\ power\ supply} \times 100\%$$

And the energy transfer rate is:

$$R = \frac{kinetic\ energy\ of\ the\ mover}{work\ done\ by\ calculated\ thrust\ force} \times 100\%$$

Experiment

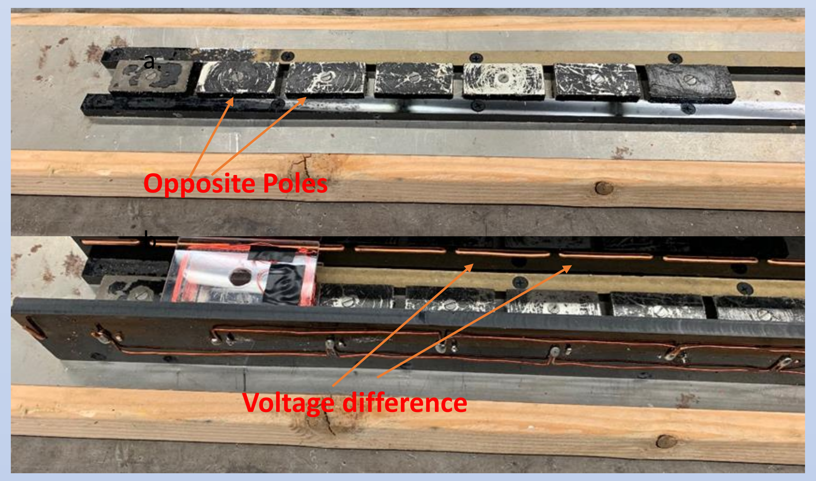

Figure.3: Picture of the stator part showing: (a) the alternating poles of magnets, (b) the arrangement of electrodes on the stator part.

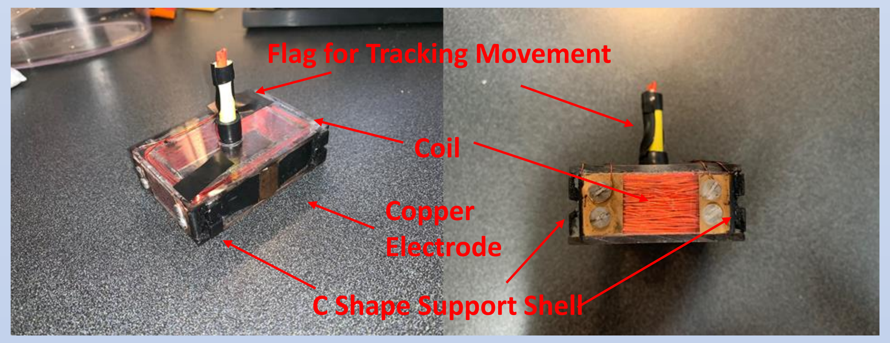

Figure.4: Picture showing the structure of the mover part. One copper electrode on each long side which help conduct current.

The motion of the mover is recorded by a camera with 240 frames per second, data points are collected by Tracker, and analyzed by Origin.

Result

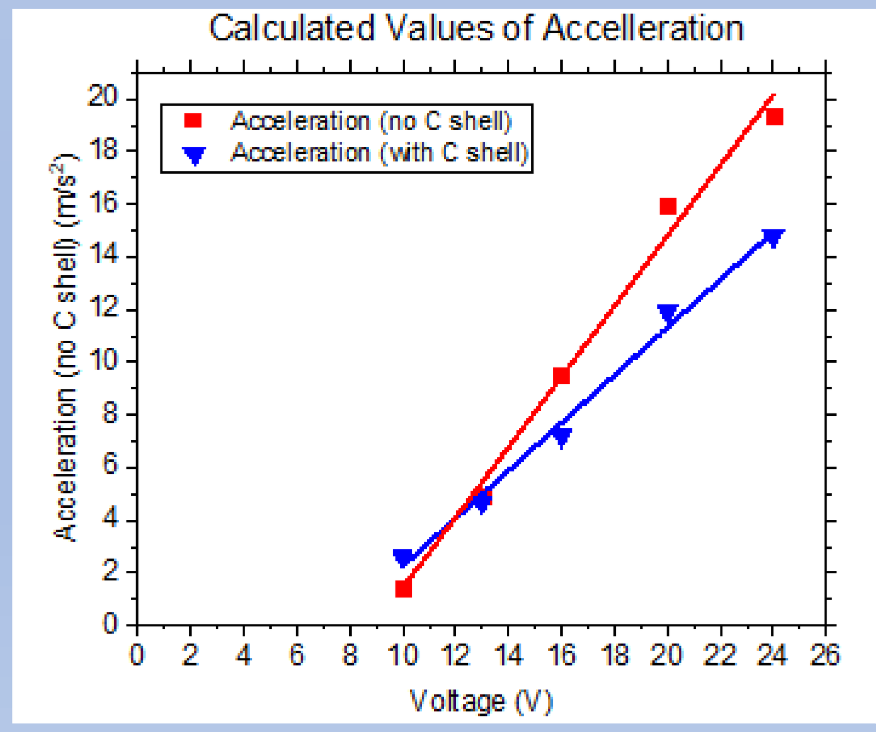

Figure.5: Calculated values of acceleration. By fitting the linear line, the y intercepts indicate the acceleration used to overcome the friction force. And the slopes represent the thrust force (not the value, just the trend)

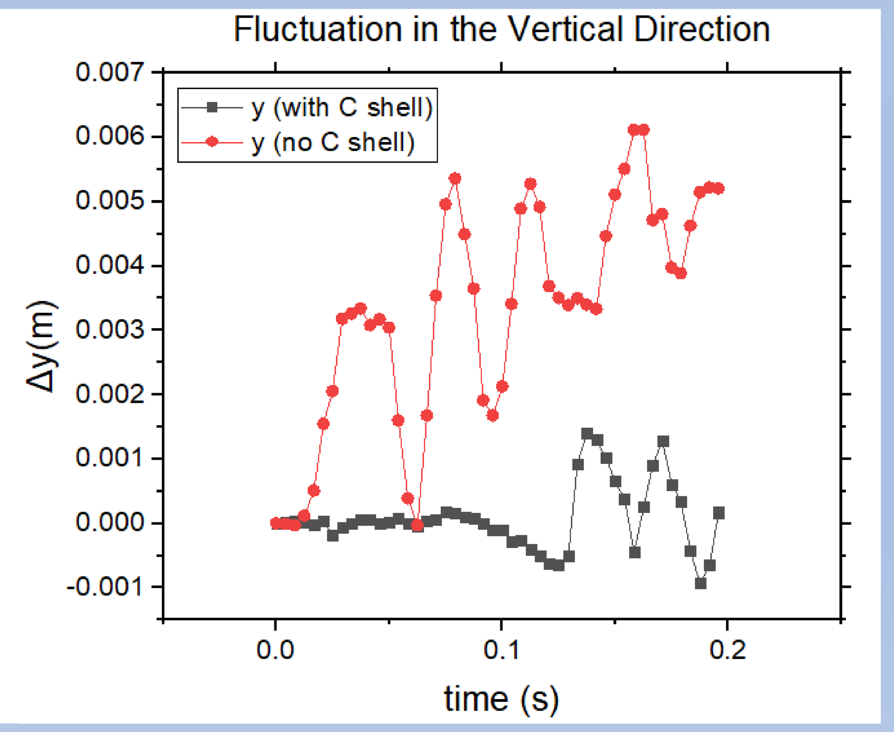

Figure.6: Measurements of the motion on vertical direction, the maximum difference is close to 6 mm (without C shell).

The C shape support shell increases the dynamic friction force of the system, which results in a lower thrust output power. However, the structure decreases the fluctuation in the vertical direction significantly (most of time less than 0.5 mm, which is not able to be distinguished with error). Thus, the C shape support shell increases the moving accuracy dramatically.

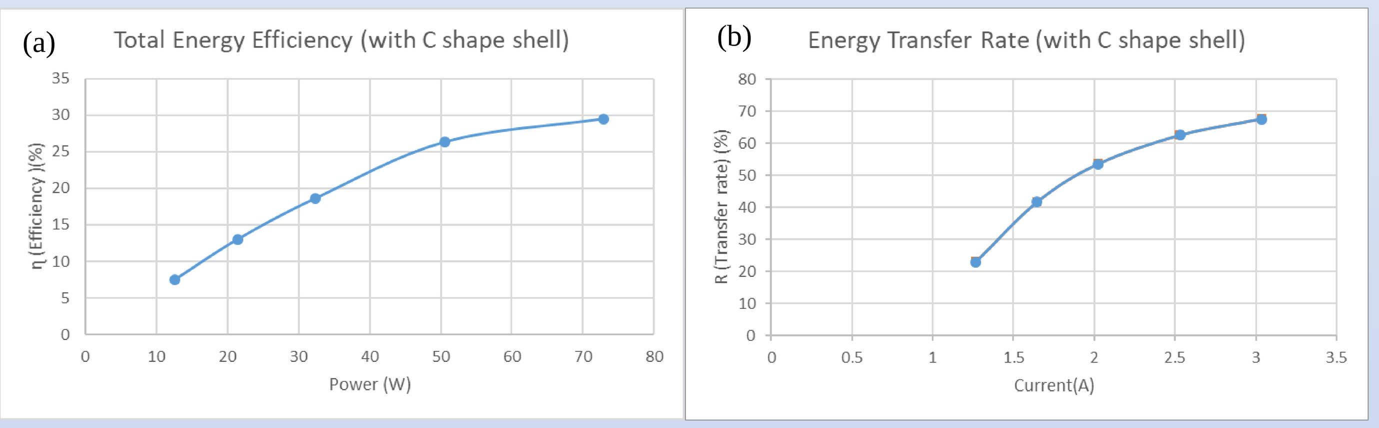

Figure.7: The calculated energy efficiency and energy transfer rate. Those two graphs suggest that the higher voltage applied to the system, it will result a higher efficiency and transfer rate. (Due to the limitation of the wire, the maximum efficiency is (a) 30% and (b) 79% energy transfer rate

The energy used to overcome friction force is nearly the same, so it can be treated as a constant, and this explains why the total energy efficiency has a linear relationship with input power.

Future Work

This system is still a prototype, more than 60% of energy is used to overcome friction force, so future work should focus more on reducing the contact friction force. In addition, a structure which is built to limit the motion of the mover is necessary, as the C shape shell increases the moving accuracy dramatically and reduces the friction a little bit. Thus, developing a better method or structure may increase those performances more.

Reference

[1]Schnibbi678. "Linear Motor Principle". *Wikimedia, Jan. 7.* 2013, https://commons.wikimedia.org/wiki/File:Linearmotorprinzip.png

Acknowledgements

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