OPENING MINDS:
RESEARCH FOR SUSTAINABLE
DEVELOPMENT

Effect of Electromagnetic Force on the Design of a Linear Alternator

W. A. D. M. Weragoda and N.T. Medagedara

Department of Mechanical Engineering, The Open University of Sri Lanka, Nugegoda, Sri Lanka

**Corresponding author: Email: wadmweragoda@gmail.com*

1 INTRODUCTION

Linear alternators are devices used to convert mechanical energy into electrical energy. Although linear alternators are used for high power generation, such as the free piston engine and the wave power generator, linear alternators that can be used for low power generation are not commercially available. This research focused on designing a linear alternator to suit low power generation needs. These low power linear alternators can be used to harness energy off exercise machines, with linear motion and even rotary motion via a crank-slider mechanism and thereby store energy in a battery for later use.

Two main factors that have to be considered when designing a Linear Alternator are the total resistance and output voltage. The total resistance depends on the inertia force and the electromagnetic force of the system. With the variation in the dimensions of the linear alternator, and the arrangement of magnets and iron rings of the linear alternator, the Magnetic flux density takes a complex form (https://www.supermagnete.de/eng/faq/How-do-you-calculate-the-magnetic-flux-density). The electromagnetic force acting on the translator is determined using COMSOL Multi-physics and the Maxwell's stress tensor to optimize the design. Several simulations were carried-out, analysed, and the method of approaching the optimum solution is presented.

There are two main factors that affect the total resistance to motion; the inertia force due to the mass of the translator and the electromagnetic force due to the magnetic flux distribution. Determining the electromagnetic force is not as straight forward as determining the inertia force. It requires solving complex equations such as Maxwell's stress tensor, utilizing software such as COMSOL Multiphysics and carrying out mesh refinements processes in order to obtain an optimized solution (Bethany, 2017).

1.1 Electromagnetic force

The electromagnetic force can be computed using two main methods, the Lorentz force and the Maxwell's Stress tensor. Since the translator is a magnetic material, Lorentz force method cannot be used to compute the force on the translator (Paudel, 2016)

1.2 Electromagnetic force calculation

The electromagnetic force is obtained by using the Maxwell's Stress tensor given in equation 1 and 2 (Bermúdez *et al*., 2016).

$$F = \int 2\pi r T n ds \qquad (1)$$

$$T_{ij} = \frac{1}{\mu_0}\left(B_i B_j - \frac{1}{2}\delta_{ij}B^2\right) \qquad (2)$$

T = Stress tensor
n = unit normal vector
B = Magnetic flux density (T)
μ_o= Permeability of Vacuum $4\pi \times 10^{-7}$
F = Electromagnetic force

1.3 Variation of magnetic flux with shape of the magnet

$$B = \frac{B_r}{2}\left[\frac{D+z}{\sqrt{{R_a}^2+(D+z)^2}} - \frac{z}{\sqrt{{R_a}^2+z^2}} - \left(\frac{D+z}{\sqrt{{R_i}^2+(D+z)^2}} - \frac{z}{\sqrt{{R_i}^2+z^2}}\right)\right] \quad (3)$$

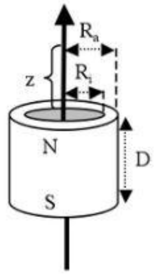

Figure 1: Dimensions of the hollow cylindrical magnet

2 METHODOLOGY

1. Several linear alternator designs such as moving iron, moving magnet and moving coil were studied and the moving iron linear alternator was selected as the design because of its advantages.

2. The linear alternator was initially designed using manual calculation from equations obtained from research papers. (Ding Wang (2016))

3. Parameters and dimensions of that design were varied and results were obtained using COMSOL Multiphysics and the results were analysed and changes were made in the design

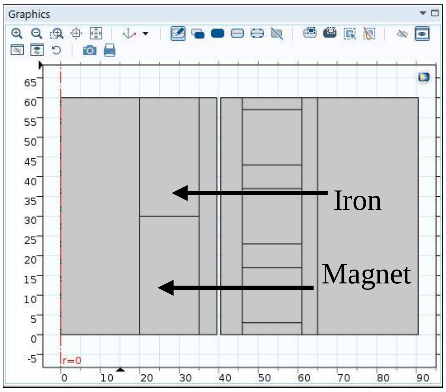

Figure 2: Geometric model of alternator

The electromagnetic force (given in equation 1) depends on the magnetic flux density as shown by equation 2. Equations 3 shows that, the magnetic flux density varies with the dimension and the shape of the magnet. These equations were used to simulate the model and optimize the design using COMSOL Multiphysics.

Figure 2 shows the 2D axis-symmetric drawing of the arrangement of the permanent magnets and irons incorporated in the linear alternator.

Figure 3 shows the way the electromagnetic force varies with the size of the magnet. This uneven variation is due to the arrangement of magnets, i.e. the pole pitch of the alternator.

The Remnant flux density of the magnets was kept constant and the size of iron and magnet was varied. When a magnet is kept near an iron, the iron is magnetized and a complex magnetic flux distribution is formed, this in turn results in the uneven variation of the electromagnetic force.

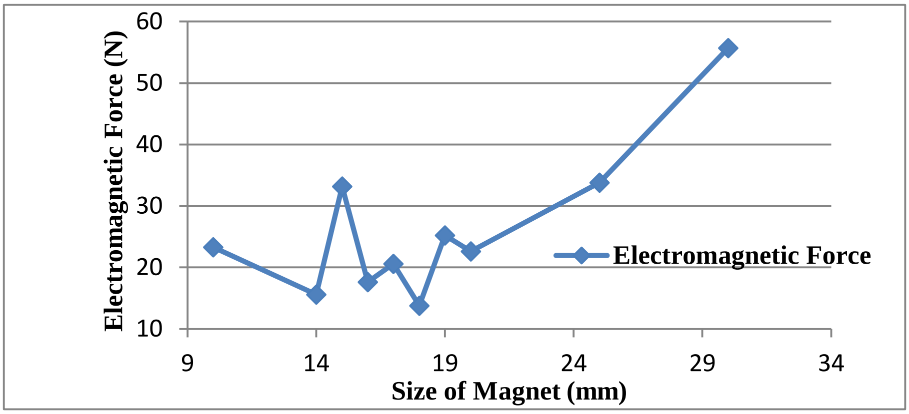

Figure 3: Variation of emf with size of magnet

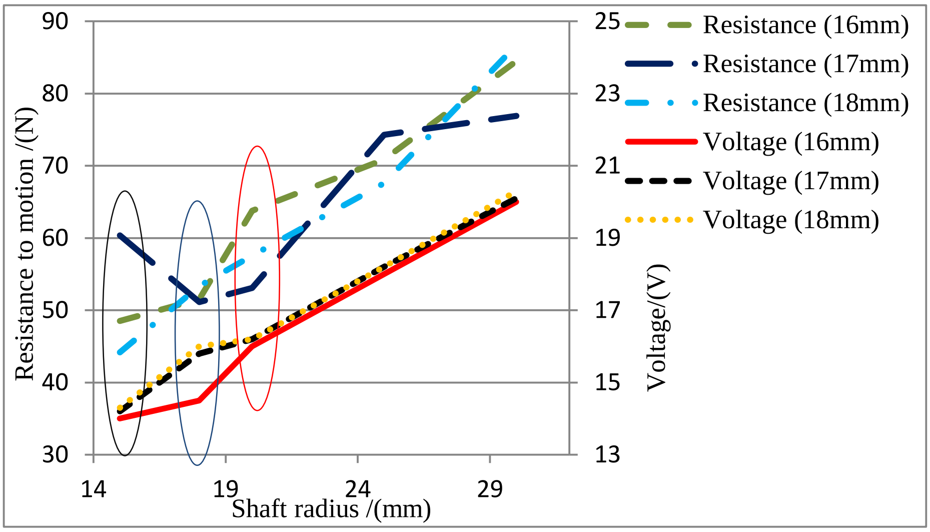

Figure 4: Graph of variation of resistance and voltage with size of the shaft

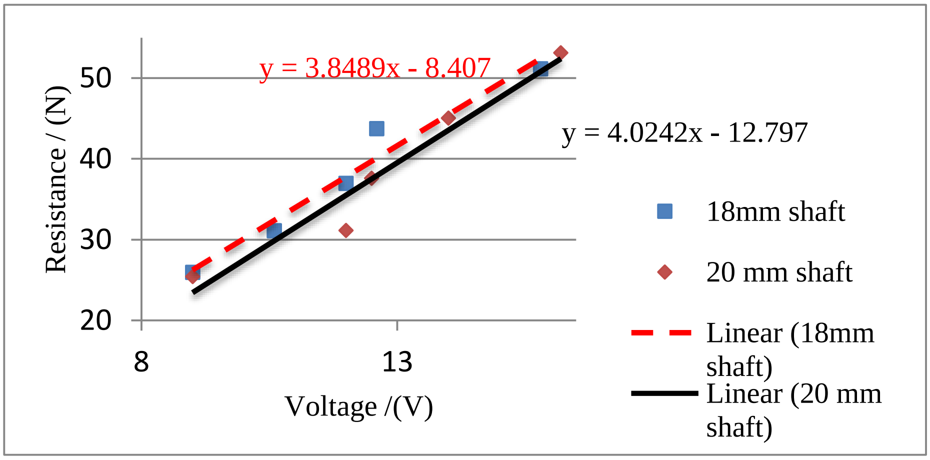

Figure 5: Graph of variation of resistance vs. voltage

Figure 4, shows the variation of the resistance and voltage with the size of the shaft of the translator. When the diameter of the shaft is changed, the inner diameter of the magnet and the iron also change. This will also change the magnetic flux distribution around the magnet, and thus, the resistance to motion. The resistances and the voltages corresponding to the encircled shaft radii were further analysed and two shaft radii were selected. The variation of resistance and voltage of both the shafts (i.e. 18 mm and 20 mm) were plotted as shown in Figure 5. The gradient of the graph of resistance versus voltage for the linear alternator model with the 18 mm shaft is less than that of the 20mm shaft. This indicates that for a unit rise in voltage the unit rise in resistance for the model of 18mm shaft is less than that of the 20mm shaft. Thus, the most suiTable design could be obtained if the 18mm shaft is used.

Figure 6 and Figure 7 show the magnetic flux distribution and the output voltage of the final design of the Linear Alternator (LA). The simulation was performed at a translator speed of 1.4 ms-1. An output voltage of approximately 14.5V was produced at this pace. And this could be utilized to charge a battery of 12V.

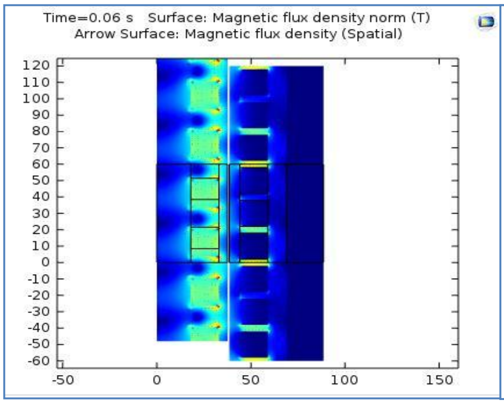

Figure 6: Magnetic Flux distribution of LA

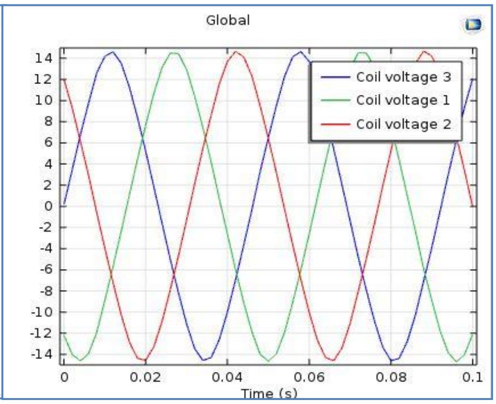

Figure 7: Output voltage LA at 1.4 ms^{-1}

4 CONCLUSIONS AND RECOMMENDATIONS

A 12V battery can be charged with an output voltage of 14.5V, as a 12V battery’s float voltage is around 2.25 to 2.3 volts/cell (at 25 degrees C) (i.e. 13.5V to 13.8V for 12V battery). The total resistance depends on the inertia force and the electromagnetic force. The total resistance is around 42 N, which is considerably low. The optimization of the linear alternator was obtained using COMSOL Multiphysics, by selectively altering parameters and comparing the best possible values to suit the design. The electromagnetic force changes with the size of the permanent magnet, iron, alternator shaft and the arrangement of magnets. Further studies and optimization could be done by simultaneously linking MATLAB and COMSOL Multiphysics to determine the reason for the uneven variation of the resistance and to obtain better solutions.

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