Generating Electricity from Mechanical Vibrations: Optimization of Linear a Generator

MAA KARUNARATHNA, KAM DHANURANGA

(Department of Electronics, Faculty of Applied Sciences, Wayamba University of Sri Lanka, Sri Lanka)

Abstract: Energy preservation is one of the key components in developing eco-friendly machines. In industry, the majority of machines lose a considerable amount of energy through mechanical vibrations. However, the wasted energy through vibration can be utilized as a renewable energy source to compensate for the overall energy loss. The research work presented in this paper discusses the ability to design a linear power generator utilizing Nd Fe-B magnets, which can generate energy through mechanical vibrations. A pilot model was developed and simulated to understand the efficiency and limitation. The results showed that the model could reduce 14% rotor bulk with a marginal impact on the current generation.

Keywords: Mechanical Vibrations, Linear Generator, Sustainable Energy, Energy Production

1 Introduction

Energy consumption and the demand for Electrical energy are increasing at an alarming rate. The estimated availability of focalized energy sources ends within 40 years as predicted, which most probably creates an energy crisis all around the globe[1-2]. All industries, social life, and almost everything in modern society depend drastically on Electrical energy. Energy preservation is essential in this scenario. Almost in any environment which consumes energy, the loss of energy as frequently unusable components as noise, heat, and vibrations is witnessed. Compensating this loss is essential. Loss of energy as mechanical vibration is visible in all most any environment. In such a case, if this wasted energy can be converted into a useful form itself, it provides a renewable energy source while compensating for the loss of power. The application of this kind of device is possible in industrial plants, roads, or any place where a considerable amount of mechanical vibrations can be witnessed. This research aims to optimize and develop a system that can absorb energy from mechanical vibrations and convert it into electrical energy using a linear power generator.

2 Theoretical Analysis

Theoretical concepts and Mathematical aspects of the designed generator were based on the Thiodelselectromagnetic field theory[4].

Oskar Danielson discusses some complications and techniques used in developing mega-scale linear generators for wave energy plants and considerations when developing a linear generator's basic structure [5].

Energy conversion presents some performance analysis mechanisms, structural optimizations, and facts considered critical in designing a linear actuator subjected to develop a linear generator[4].

Miniaturization of this linear structure has been a worldwide attempt ever since. Many researchers had their leads and drawbacks of the presented designs. Paper presented in SICE Hokkaido highlighted a promising small-scale generator, later adopted for installation in motor vehicles and development published in Journal of Asian Electric vehicles[5-6].

2.1 Linear Power Generators

The fundamental structure of the linear power generator is classified broadly into two types with magnets and plungers that linearly actuate; the line actuation type magnet and the straight line actuation type plunger[2]. The basic structure of this power generator is mentioned in Fig.1; unlike the conventional induction generators, leaner generators have a stator and a mover. The stator consists of the coils, while the mover consists of the current and ferromagnetic case. It is a common practice that the mover has permanent button magnets. In between, the button magnets contain a ferromagnetic layer.

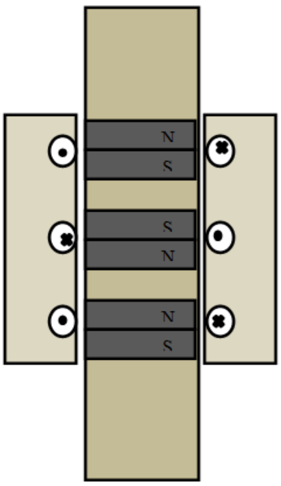

Fig.1 Structure of a Linear Generator

Mover is made up of magnets in which the same magnetic poles are facing each other. This placement helps generate a magnetic field perpendicular to the axis of the stator, creating a perpendicular magnetic field for the coil windings.

2.2 Multi Phased Systems

In almost every generator, coil windings are composed of several parallel windings with parallel circuits. Those are mutually phase-shifted on intervals of even electric periods. A single circuit like this is referred to as a single passed system. Since the produces power varies drastically in a single-phase system, the most common approach is a three-phase system that is shifted over $2\pi/3$ electric periods. This benefits the constant power production from the generator.

2.3 Problems with Linear Generators

The state-of-art linear generators for wave energy conversion have some disadvantages. These are as follows

- Physically limited efficiency
- Large and expensive
- The bearing loads are large, and the bearings are not maintenance-free[7].

However, the size of the generator is significantly reduced in small-scale products, so in this context size of the generator and the cost will not be an issue. The bearing load is important on any scale because the linear generators associate a considerable amount of weight in the bearing, and mover consists of permanent magnets and mild steel intersections.

When it comes to small-scale designs, the following factors heavily affect the design's performance and should be carefully considered.

- Eddy currents
- Reactive losses
- Resistive losses

3 Design & Implementation

Major drawback of the earlier design was the weight of its mover; stator consists of permanent magnets and mild steel plates between them. Heavy stator results in quick deformation of equipment. It is a considerable challenge to compensate weight reduction of the rotor without a significant effect on the linear generator performances. Approach to the weight reduction will be reducing the weight and the size of the magnets.

Another approach to reduction of weight would be fixing the coil to the mover. This also has its own drawbacks. Since the coil is moving the induced electricity should be transferred via slider mechanism, through contact sliders. This is resulting in unavoidable power loss and possible deformation of sliders resulting in frequent maintenance.

Reducing the size of the magnets is a solution. But it is unavoidable that with the size reduction there will be field strength loss.

Induced voltage can be maximized through increasing the number of turns of the coil, this will not affect the rotor weight since the coils are placed in the stator. One restriction comes in to play the effective width of the poles are limiting the area which the coil can be turned. A solution would be to increase the effective area of the pole.

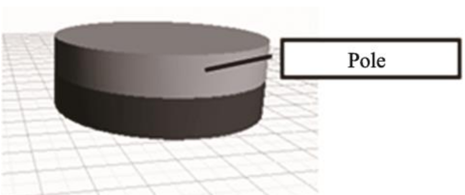

Fig.2 Button Magnets Used in Conventional Generators

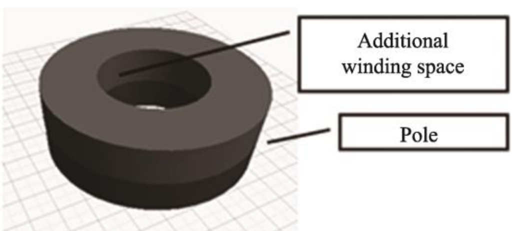

Fig.3 Proposed Ring Magnet for new Design

The effective area of the generator is the cylindrical surface of the button magnet/cylindrical magnets. This surface is where the coil is turned parallel to the surface. Instead of using button magnets, we can use cylinder magnets with the exact outer dimensions and maximize the effective pole area.

Reduction of magnet volume will affect the power generation, but this can be reasonably compensated using stronger magnets with an increases number of windings with additionally available internal winding space.

3.1 Design of the Stator

Rotor consists of ferromagnetic rod and mild steel cylinder. Design of the rotor starts with defining the materials used and potential magnetization it could handle. This aids in deciding the magnetic strength which could be used.

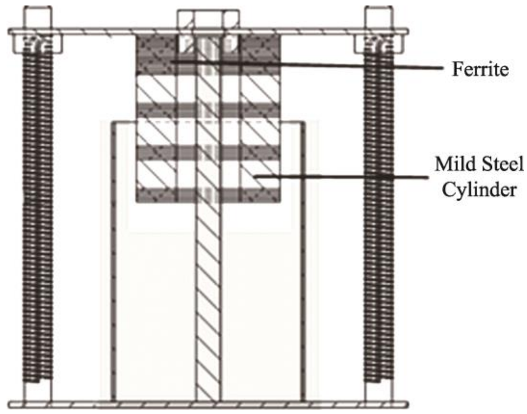

Fig.4 Design of the Stator

3.2 Design of Mover

Mover consists of Nd Fe-B magnets, in which the magnets are placed in a manner that same pole face the other. Magnets were placed with the same periods of the coil winding. Mild steel materials are made out of mild steel rings. Four mild-steel rings separated the three Nd Fe-B ring magnets used in the pilot model, each made of sheet metal. The Topmost contained fifteen sheet metal rings and the rest five sheets each. However, the number of magnets can be increased with the extension of the stator rod and casing.

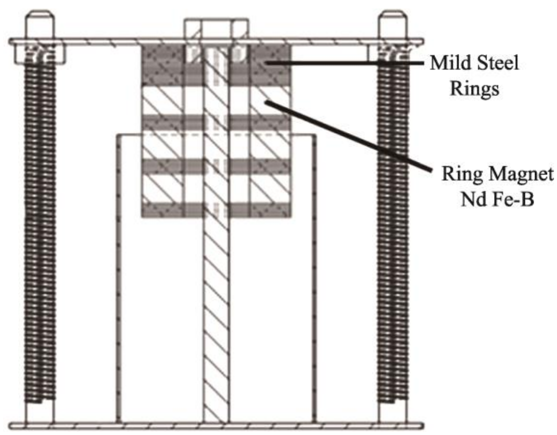

Fig.5 Design of the Mover

The mild steel frame was placed to guide the magnetic flux through the frame of the stator.

3.3 Simulation of the Stator Arrangement

Flux generation and induction were simulated using Elmer software after generating the CAD file using solid works. Simulation of magnetic flux with and without the mild steel frame and ferrite rod is in Fig.6 and 7.

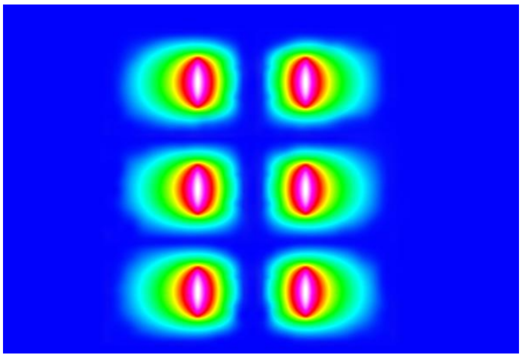

Fig.6 Flux with No Ferrite Rod or Mild Steel Frame

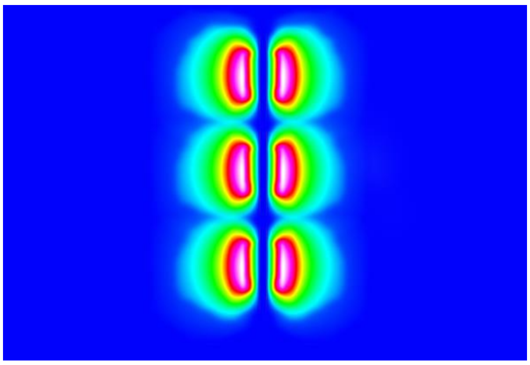

Fig.7 Flux with Mild Steel or Ferrite Frame

Fig.6 shows the magnetic flux simulation of the stator without ferrite rod and the mild steel case of outer winding.The flux seems to be more outspread from the magnetic surface.Fig.7 shows the simulation of stator magnets with the ferrite rod and the mild steel case of outer winding.Flux lines are a bit moreguided along with the mild steel case and the ferrite rod. The flux distribution is more collapsed and contained, providing the optimum flux density of intertwined coils.

3.4 Specification of the Modeled Magnets

- Material: Nd Fe-B
- Outer Diameter: 54mm
- Inner Ring Diameter: 23mm
- Thickness: 10mm
- Flux Density = 400 mT
- Adsorption power = 26.0 Kgf

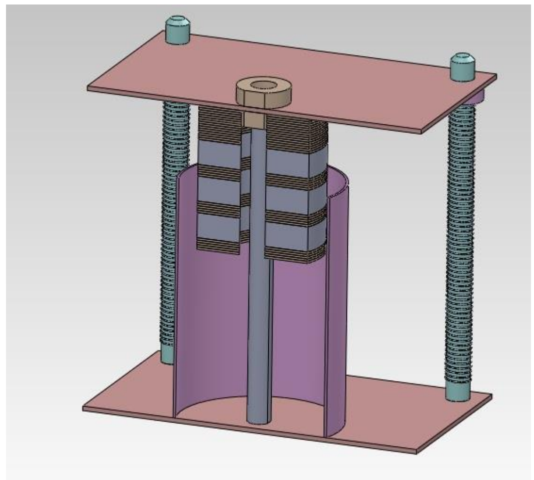

Fig.1 Designed Generator - Simulation Cross Section

Specifications of the center rod (diameter was varied with the test simulations)

- Length: 107mm
- Diameter: 12.7mm
- μ = 800 H/m

Specifications of the outer winding steel (diameter was varied with the test simulations)

- Material = Mild steel
- Thickness = 1mm

3.5 Pilot Generator Design

In designing the pilot generator, a standard ferrite size (12.7mm) was used. The air gap width was adjusted by introducing a thin non-inductive sheet between the ferrite and the coil. The same procedure was followed with the outer mild steel sheet.

4 Results & Discussion

4.1 Generated Voltage

The simulation results for the designed generator under a frequency of "1Hz" are mentioned in the graph.

4.2 Current Variations

The plot simulated over an imaginary load of 75 Ohms. The maximum obtainable current is around 6.7mA, which is a considerable value for the new design over previous ones.

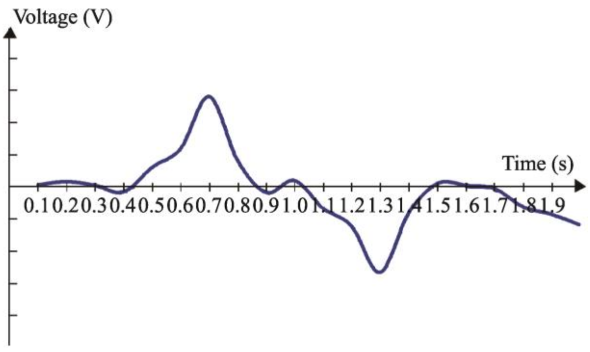

Fig.9 Simulator Voltage Graph

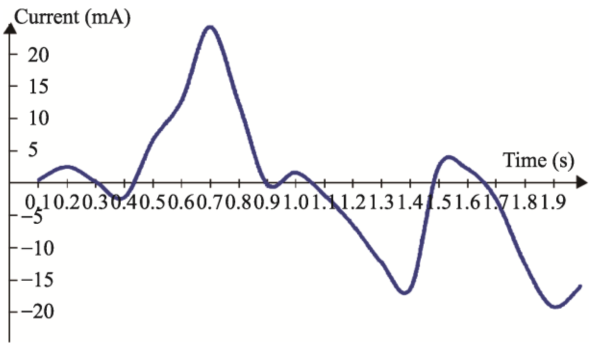

Fig.10 Simulator Voltage Graph

Table 1 Results Comparison

Parameter	Existing Module	Current Design	Pilot Module
Average Bulk Weight of the Mover. (Per Unit Magnet)	59.6496g	51.282g	58.212g
Magnet Adsorption Power	400 mT	400 mT	~130mT
Peak Current [Max Power Point]	25mA	23.85mA	2.5mA
Peak Voltage	1.75V	2.01V	0.745V

The current characteristics of the existing module and the new development are almost the same at simulation, but the pilot generator has some severe deviations. This was mainly because of the lack of adsorption power and the lower flux density of the alloy ceramic magnets.

The bulk of the rotor is reduced from 13.77% with a current percentage loss of 4.6 with a voltage performance increase of 15.4%. However, the performance of the pilot generator can be used as proof of the induction capability of the new design.

5 Conclusions

Optimization of small-scale linear generators was studied in this research study. Further, addressing the challenges of reducing weight, changing stator and rotor orientations to reduce the loss of power due to slider contacts, and reducing the wear and tear parts of the model was discussed.

5.1 Limitations and Drawbacks of the Current Design

- The system cannot stand more than a temperature of 150C. If the temperature exceeds the limit, the Nd Fe-B magnets start to lose their magnetic characteristics. This is valid for the existing system as well. The equipment cannot be installed in case of a high frequency operation or in machinery with extensive heat dissipation.
- Purchasing of Nd Fe-B magnets is expensive in small quantities, cheaper in large quantities.
- Nd Fe-B magnets pose a threat to the environment with their chemical composition of neodymium.
- Not suitable for a high-frequency operation since the reactance losses considered negligible in the low frequencies, will become dominant at high frequencies.
- Mechanical vibration does not show a continuous oscillation since the generated voltage will be hard to regulate efficiently.

5.2 Further Development and Research Opportunities

- A more temperature resilient model is required for high-frequency operation. The model could be developed using more temperature resilient magnets to obtain suitable voltage and current characteristics in a high-temperature environment.
- The model could be developed or altered to

be more reactive resilient and control the eddy current losses simultaneously.

References

[1] B. K. Sovacool, How long will it take? Conceptualizing the temporal dynamics of energy transitions, *Energy Research & Social Science*, Vol. 13, 202-2015, 2016.

[2] P. A. Owusu, S.A. Sarkodie, A review of renewable energy sources, sustainability issues and climate change mitigation, *Cogent Engineering*, Vol. 3, 2016.

[3] W. Abrahamse, L. S. C. Vlek, T. Rothengatter, A review of intervention studies aimed at household energy conservation, Journal of Environmental Psychology, Vol 25, 273-291, 2005.

[4] T. M. Gür, Review of electrical energy storage technologies, materials and systems: challenges and prospects for large-scale grid storage, Energy & Environmental Science, Vol 11, 2696-2767, 2018.

[5] K. Holmberg, A. Erdemir, Influence of tribology on global energy consumption, costs and emissions. Friction, Vol 5, 263-284, 2017.

[6] R. G. Horn, D. T. Smith, Contact electrification and adhesion between dissimilar materials. Science, Vol.256, 362-364, 1992.

[7] K. Sayfidinov, S. D. Cezan, B. Baytekin,H. T. Baytekin, Minimizing friction, wear, and energy losses by eliminating contact charging, Science Advances, Vol 4, 11, 2018.

[8] Oskar danielsson, Design of a linear generator for a wave energy plant, *Uppsala University publication*, 2011.

[9] Boldea I., and S. A. Nasar, Linear electric actuators and generators, *IEEE Trans. Energy Conversion*, 14, 3,712-717, 1999.

[10] Takahara K., H. Nozaki, K. Kawaguchi, and Y. Ito, Prototype of a Linear Power Generator, *Proc. 34th.Hokkaido Chap. SICE.*, 101-102, 2004.

[11] Takahara K., S. Ohsaki, K. Kawaguchi and, Y. Ito, Development of linear power generator: Conversion of vibration energy of a vehicle to electric power, *Journal of Asian Electric Vehicles*, Vol. 2, No. 2, 639- 643, 2004.

[12] H. Polinder, M.A. Mueller, M. Scuotto and M. Goden de Sousa Prado, *Linear generator systems for wave energy conversion*, chp 04, 03.

Author Biographies

MAA KARUNARATHNA. received his M.Phil. degree from department of Electronics & Telecommunication Engineering, University of Moratuwa, 2007 and Ph.D. from department of Electronics, Wayamba University of Sri Lanka, 2020. He is currently working as a senior lecturer at department of Electronics, Wayamba University of Sri Lanka.

Email: asanka_eltn@wyb.ac.lk

KAM DHANURANGA. received his B. Sc joint major degree from faculty of Applied Sciences, Wayamba University of Sri Lanka and M.Sc. in Applied Electronics at University of Colombo.

Email: malithdhanuranga@gmail.com

Copyright: © 2021 by the authors. This article is licensed under a Creative Commons Attribution 4.0 International License (CC BY) license (https://creativecommons.org/licenses/by/4.0/).