Design and Analysis of a Small Scale Generator for the Portable Power Pack

H.G. Jeong[*], K.C. Kim[*], N.J. Jeong[*] and J.H. Lee[**]

[*]Korea Institute of Energy Research,
71-2, Jang-Dong, Yuseong-Ku, Daejon, Korea, hgjeong@kier.re.kr
[**]Seoul National University, Korea, jleenano@snu.ac.kr

ABSTRACT

Miniaturization of the electronic devices has steadily reduced both the size and the cost. But a power density of battery has not increased a lot. Batteries are a prime agent to penetrate and expand of ubiquitous life. But their intrinsically low energy densities and short lifetimes impose a fundamental limitation. Due to this reasons, a small linear reciprocating engine and electric generator are designed for a portable power pack in this paper. If an engine is used solely to produce electrical power in a portable power pack, it is not necessary to convert the reciprocating linear motion of the piston to rotary motion. Instead, a linear electrical generator may be coupled directly to the piston for a conversion of mechanical energy into electrical energy. Such a design has many advantages such as mechanical simplicity and low friction and it can make possible a small engine having high efficiency.

Keywords: battery, portable, power pack, linear engine, generator,

1 INTRODUCTION

In the past, the range of application of portable electronic device was limited relatively low power consuming, small sized products such as beepers, cassette players and CD players. However, recently, due to rapid development of IT(Information Technology), it is being widened to cover various products, even large sized products, such as MP3 players, portable handsets, digital cameras, portable game machines and even notebook computers. More recently, many researchers are concerned with attempts to integrate such portable devices in one unit and there exits some integration technologies. However, the most important issue that is yet to be solved is to development of a portable power supply with a sufficient capacity. Since characteristics of portable devices require convenient movement of the unit, we have to design a power supply with a high energy density per given volume, which facilitates as much reduction of its volume and weight as possible. We have already reached the limit of possible integration of energy in existing batteries. Now, we must develop a power supply of a totally new concept.

There are some existing technologies to use micro fuel cells or micro turbine to replace the existing batteries. However, they tend to require very complex processing leading to higher unit costs. In addition, since such products take advantage of MEMS technology, its yield rate and durability are too difficult to apply to commercial products.

Therefore, in this study, we would like to propose a portable power pack of a new concept, which is simple to manufacture and highly durable and design a generator suitable for such a unit. Fig. 1 illustrates the organization of the newly proposed portable power pack.

The newly proposed portable power pack includes the mini engine, the fuel supply unit supplying fuel to the engine, the mini generator transforming mechanical movement to electrical energy and finally the storage unit that can cope with a sudden change in the load. In this paper, we would like to design a linear generator applicable to the mini portable power pack and investigate the performance of such a unit through our simulation.

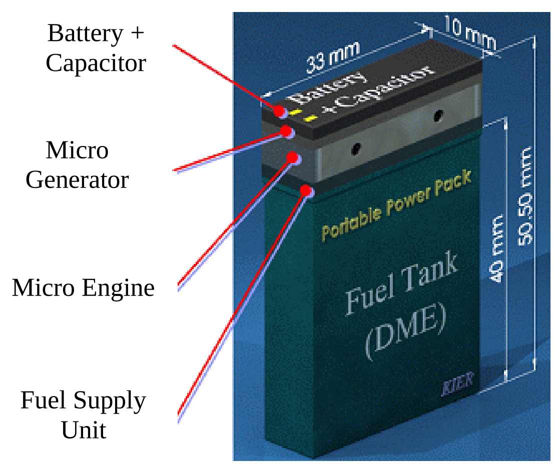

Figure 1: Organization and size of a mini portable power pack

2 DESIGN OF A MINI GENERATOR

2.1 Initial Model Setting

The magnetic field varying with time generates electromotive force(emf) that flows current in the closed circuit existing in it. This induced electromotive force is the voltage arising in a conductor when it is moved inside the magnetic field or the magnetic field is changed. Such a phenomenon can be represented by Faraday's law as shown in the equation (1).

$$emf = -\frac{d\lambda}{dt}[V] \qquad (1)$$

where λ denotes the magnetic flux and t denotes the time. That is to say, the induced electromotive force is equal to the rate of change in the total magnetic flux and it has a negative polarity.

A design of a generator for portable power packs may start with the initial design as shown in Fig. 2. As shown in Fig. 2, in order to minimize the time required for analysis, we perform a half-model analysis. The yoke of the generator for the portable power pack is limited to a given volume(20*mm* × 10*mm* × 20*mm*). Since its structure is relatively simple, the five design parameters and(X_1~X_5) another one represented by the number of coil turns(X_6) may determine the final figure. Through several sessions of symbol analysis, the initial value for the porosity is determined to be 0.25*mm* while the height of the yoke(X_1) and the magnet(X_2), the polarity height of the moving unit(X_3), the width of the magnet(X_4), the polarity height of the yoke(X_5) and the number of coil turns(X_6) are determined to be 3*mm*, 3*mm*, 1*mm*, 3*mm*, 4*mm* and 400 turns respectively. The air gaps between moving yoke and the magnets of the stator are 0.25 *mm*.

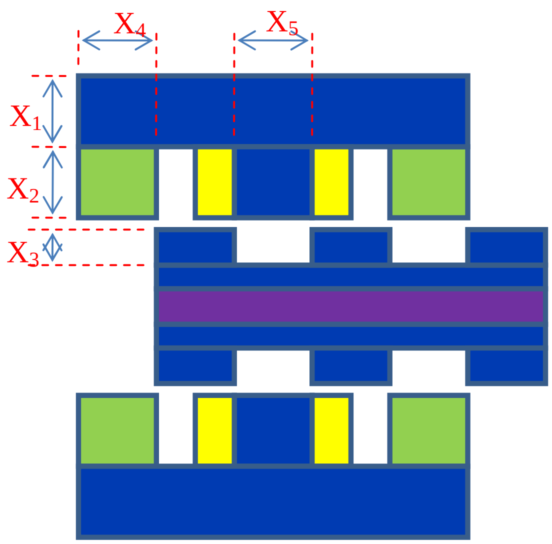

Figure 2: Initial design of a generator unit

Parameter	Symbol	Value	Unit
Yoke height	X_1	3	*mm*
Magnet height	X_2	3	*mm*
Moving unit	X_3	1	*mm*
Magnet width	X_4	3	*mm*
York width	X_5	4	*mm*
Number of turns	X_6	400	*turns*

Table 1: Initial values for the parameter

2.2 Material Properties

In the previous section, an analysis model was provided. In this section, we would like to define the material properties used for the analysis. First, a steel sheet(50H1300) for the yoke and the moving unit in order to minimize loss of iron. Fig. 3 represents the non-linear B-H characteristics of 50H1300. In our finite element analysis, a non-linear analysis is performed by using the above B-H characteristics.

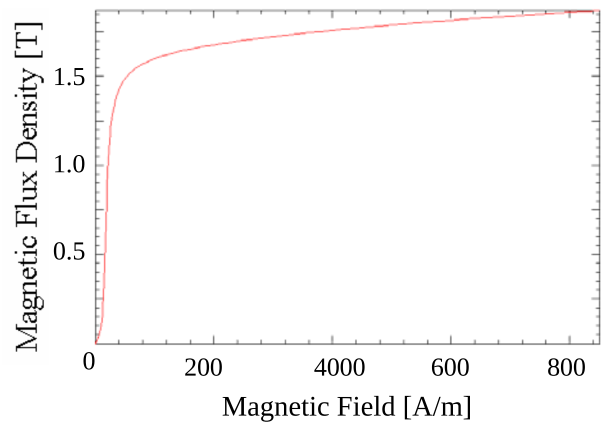

Figure 3: B-H characteristics of 50H1300

The permanent magnet is made of Nd-Fe-B and its surface magnetic flux density is assumed to 1.3*T*. The change in the surface magnetic flux density varying with time is neglected. The speed of the moving unit is assumed to be ±11.31*m/s* while it is assumed to generate a pulse waveform at constant speed. As shown in Fig. 4, the number of coil turns is 400 turns while the internal resistance is 2 ohms and the sensing resistance used to measure the voltage is 10 ohms. The upper(or lower) circuit shown in Fig. 4 represents the upper(or lower) yoke shown in Fig. 2.

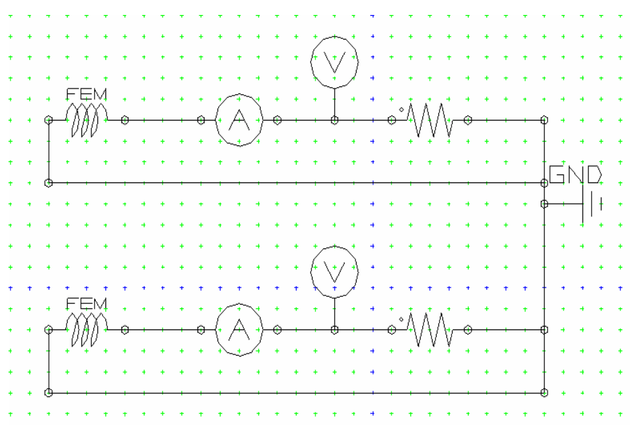

Figure 4: Electrical circuit used in the FEM analysis

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2.3 Optimal Design of a Generator Unit

Through several sessions of basic analysis, the six design parameters(X_1~X_6) are determined and their initial values are provided in the previous chapter. Based on this initial design, the optimal design is now performed. Since it is involved with the magnetic field induction, a 3-D analysis is performed. In order to reduce the time necessary for the analysis, a half-model based analysis is performed.

The optimal function is the equation 2 and the boundary conditions is from equation 3.

$$f = \sum \left| i_{induced} \right| \tag{2}$$

$$\begin{aligned} &g1 : X_1 + X_2 + g + X_3 + 1 \le 9 \\ &g2 : 1.5 \le X_1 \le 4.5 \\ &g3 : 1.5 \le X_2 \le 4.5 \\ &g4 : 0.3 \le X_3 \le 3.0 \\ &g5 : 1.5 \le X_4 \le 4.5 \\ &g6 : 2.0 \le X_5 \le 5.0 \\ &g7 : 100 \le X_6 \le 500 \end{aligned} \tag{3}$$

This problem of optimization requires a constraint shown by g1 since the sum of the induced current should be maximized while satisfying the yoke volume given by $20mm \times 10mm \times 20mm$. The remaining constraints *g2* through *g7* are constraint specifying the range of each design parameter.

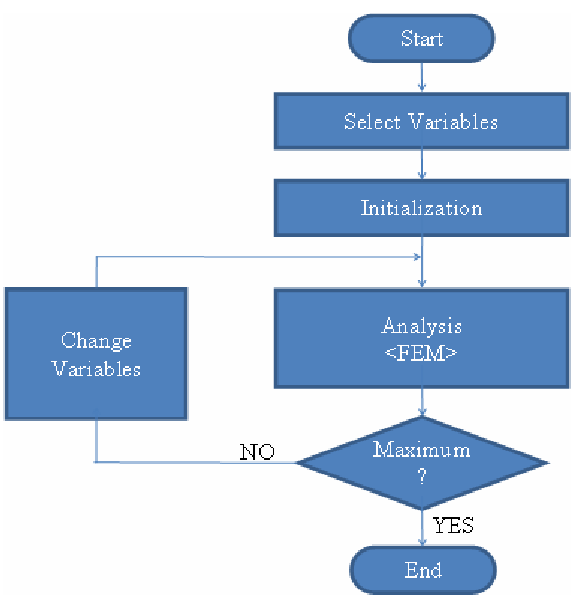


Figure 5: Flow chart for optimal design

After running the simulation for 604 times, the final design parameters are obtained as Fig. 6 and Table 2.

Fig. 7 illustrates a comparison between magnetic flux lines obtained in the alignment condition and the non-alignment condition. In order to minimize the magnetic flux line in the non-alignment condition, the separation between the yoke's pole and the magnet is almost same as the width of the poles of the moving unit. In the alignment condition, in order to maximize the magnetic flux line, the width of the magnet is almost same as the width of the pole of the yoke.

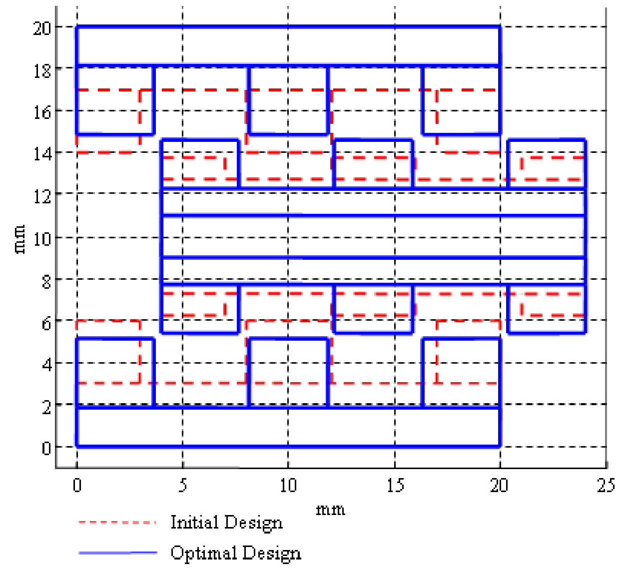
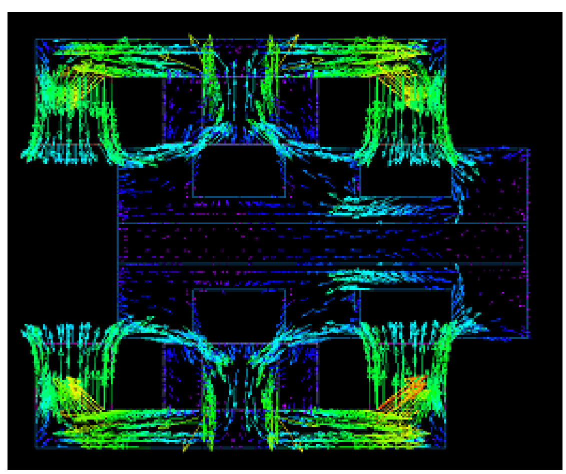


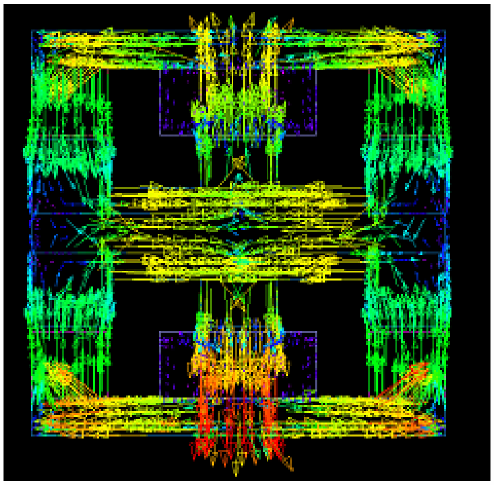
Figure 6: Optimal Design parameters

Parameter	Symbol	Value	Unit
Yoke height	X_1	1.85	*mm*
Magnet height	X_2	3.28	*mm*
Moving unit	X_3	2.36	*mm*
Magnet width	X_4	3.66	*mm*
York width	X_5	3.68	*mm*
Number of turns	X_6	300	*turns*

Table 2: Optimal Design parameters



(a)



(b)

Figure 7: Magnetic flux densities (a) in the non-alignment condition (b) in the alignment condition

Fig. 8 and Fig. 9 represent the induced voltage and current. The initial design values are represented by the dotted lines while the optimal values are represented by the solid lines. In Fig. 8, the induced voltage is somewhat reduced but as the less number of coil turns reduces the inductance, the resulting induced current is increased as shown in Fig. 9. The optimal induced current shown in Fig. 9, is increased by 25% from the peak value of the initial design value while it is increased by 43% from the RMS value of the initial design value.

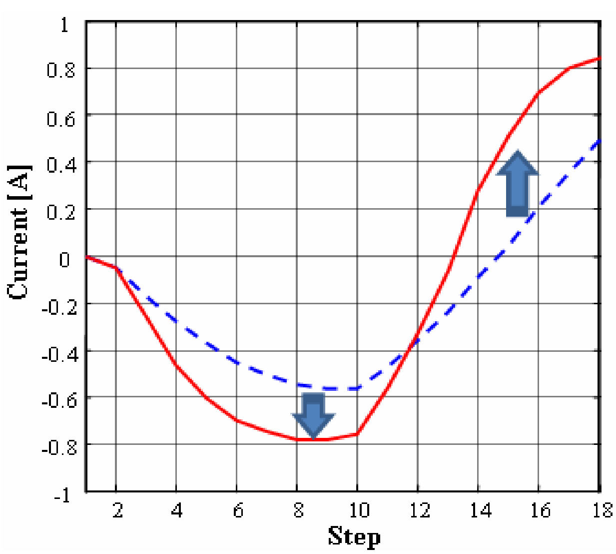


Figure 8: Waveform of the induced voltage

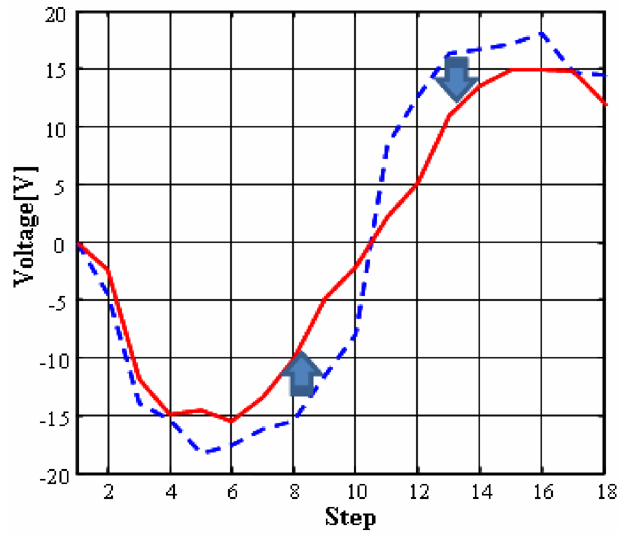


Figure 9: Waveform of the induced current

3 CONCLUSION

Through our FEM analysis, we performed a design of a generator for the mini portable power pack. Since the induced voltage increases in proportional to the change in the magnetic flux across the coil, the resulting design reflects such a change. As shown in Fig. 6 and Table 2, the width of the yoke(X_1) tends to get thicker in order to prevent saturation of the magnetic flux. To minimize the magnetic flux that does not pass through the pole, the height of the moving unit(X_3) tends to get higher. In addition, the width of the magnet(X_4) and the yoke(X_5) are almost identical to each other. As a result, the induced voltage is slightly reduced. However, as the number of coil turns is decreased, the optimal induced current is increased by 25% from the peak value of the initial design value while it is increased by 43% from the RMS value of the initial design value.

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