"DESIGN AND DEVELOPMENT OF HUMAN POWERED GENERATOR FOR PORTABLE ELECTRONIC EQUIPMENT"

A Major Project Report

Submitted in Partial Fulfillment of the Requirements

Of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(POWER APPARATUS & SYSTEMS)

Submitted By

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DEPARTMENT OF ELECTRICAL ENGINEERING

AHMDABAD – 382481

CERTIFICATE

THIS IS TO CERTIFY THAT THE MAJOR PROJECT REPORT ENTITLED "DEVELOPMENT OF HUMAN POWERED MICRO ELECTRIC GENERATOR" SUBMITTED BY MR. RAJESH KUMAR GUPTA (05MEE013) TOWARDS THE PARTIAL FULFILLMENT OF THE REQUIREMENTS OF PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR MASTER OF TECHNOLOGY IN ELECTRICAL ENGINEERING WITH SPECIALIAZATION IN POWER APPARATUS & SYSTEMS OF NIRMA UNIVERSITY OF SCIENCE AND TECHNOLOGY IS THE RECORD OF WORK CARRIED OUT BY HIM/HER UNDER OUR SUPERVISION AND GUIDANCE. THE WORK SUBMITTED HAS IN OUR OPINION REACHED A LEVEL REQUIRED FOR BEING ACCEPTED FOR EXAMINATION. THE RESULTS EMBODIED IN THIS MAJOR PROJECT TO THE BEST OF OUR KNOWLEDGE HAVE NOT BEEN SUBMITTED TO ANY OTHER UNIVERSITY OR INSTITUTION FOR AWARD OF ANY DEGREE OR DIPLOMA.

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CERTIFICATE

This is to certify that Project Report entitled "**Design and Development of Human Powered Electric Generator for portable electronic equipment** " is being submitted by Mr. Rajesh Kumar Gupta (05MEE013) as a partial fulfillment of the requirement for the award of Degree of **Master of Technology** in Electrical Engineering in the field of **Power Apparatus & Systems** awarded by Institute of Technology, Nirma University of Science and Technology embodies work carried out by her under my supervision at **Industrial Electronics Group**, **Central Electronics Engineering Research Institute, Pilani** (Rajasthan) during the period from **June, 2006** to **April, 2007**.

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Abstract

A system is proposed to design a vibration based micro generator that uses a mass spring system attached with a coil to convert mechanical energy to electrical energy by faraday's law of induction. The goal of our research is to create a minimum sized electric power generator, which is capable of producing enough voltage to operate cellphone and other low power devices. Thus far we want to produce a 3.6-volt DC with very low frequencies and low vibration amplitude such as 3 to 5 Hz frequency and 2 to 5mm vibration amplitude. A comparison of performance between theoretical and practical generated voltage is also shown. Other applications for this generator are heart-pacers, power source for VLSI system design, military survival systems and robotics systems etc. Now with growing interests and technologies we believe that our human powered generator will find many other applications in future.

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Human Powered Electric Generator

Specifications:

Input Amplitude of Vibration = 2 to 5mm
Input Frequency = 2 to 5 Hz
Output Power = 15 mW

1. INTRODUCTION

1.1 General

In recent years electronic circuitry has continue to decrease in size, achieving more and more applications in single product. So the power consumption of products is also rapidly decreasing. Most of the portable equipment such as FM/AM radio, Walkman, remote controller, communication sets; mobile phone etc is fitted with the rechargeable batteries. Most of the rechargeable batteries provide power for 12 to 48 hrs depending on application and type of battery technology. The short duration power availability of rechargeable batteries has resulted in the need of utilization of available source on sight for portable equipment. Various Techniques such as solar power, Hand operated generator, thermoelectric generator and piezoelectric generator are investigated for portable power generation. Out of this human powered generator seems to most viable solution as user himself can generate power as where and when required. it will be a great achievement if we are able to develop a device that can charge our batteries without any power supply. Renewable power supplies convert energy from an existing source in the environment to electricity. Some of the possible energy sources are

- Light energy from ambient light such as sunlight.
- Thermal energy: thermoelectric generators generate electricity when placed across a temperature gradient.
- Volume flow i.e. flow of liquid or gases.
- Mechanical energy that is energy from movement and vibration.

Electric power generators based on mechanical vibration are broadly classified as:

- Piezoelectric type: this type of generator using piezoelectric material to convert strain (pressure) to electricity.
- Electromechanical type: Generation of electrical energy by the movement of magnet inside a coil by the mechanical motion of spring due to vibration.
- Electrostatic type: an electret's arrangement with a permanent magnet embedded in the mass induces a voltage on the plates of a capacitor as it moves.

1.2 Literature summary of relevant technical papers:

1. **Yates *et al.*** of Sheffield University have constructed an electromagnetic MEMS VDRG, capable of generating 0.3-microwatt power from a 4.4-kHz 500-nm input motion. Their device consists of a moving magnetic mass mounted on a flexure, which allows a change of flux linkage with a coil deposited beneath the moving mass[1].

2. **Chandrakasan *et al*.** of MIT have constructed both an electrostatic CDRG based on a comb-drive, which generates 8 microwatt from a 2.5-kHz 500-nm input motion, and a larger electromagnetic VDRG, where they simulate approximately 400microwatt root-mean-square (rms) power for an input motion, which represents human walking. The test chip integrates an ultra low power controller to regulate the generator output voltage using delay feedback techniques, and a low power sub band filter DSP load circuit. This chip is integrated in 0.8micrometer CMOS process.

3. **Li *et al*.** of the Chinese University of Hong Kong have constructed and tested a MEMS electromagnetic VDRG. They generate 40microwatt from an 80-Hz 200micrometer input vibration. They have successfully

demonstrated data transmission powered by this source using a standard infrared transmitter running at a low duty cycle[3].

4. **White *et al*.** of S0outhampton University have constructed a MEMS piezoelectric VDRG [11], [17], [18] capable of generating 2.2microwatt from a 0.9-mm 80-Hz input motion[3]

5. **Tashiro *et al*.** have constructed an electrostatic CDRG. This is not MEMS, or even miniature generator, weighing 0.64 kg[3].

6. **M.EI-hami *et al*** Southampton university , Department of electronics and computer science constructed a electromagnetic generator based on the relative movement of a magnetic pole with respect to a coil and it is capable of generating power generation of 1mw within a volume of 240mm^3 at a vibration frequency of 320 Hz[4].

7. **Johnny M.H**. Lee *et al.* proposed an AA size vibration induced micro energy transducer with a power management circuit. A power management circuit is used to step up the ac output voltage and acts as a reservoir to store the electric energy generated. This have proposed a generator which is capable of producing 4.4volt peak to peak and 680 microwatt with input vibration frequency ranging from 60 to 110 Hz with 200micrometer amplitude[5].

8. **P.Glynne-Jones *et al*** describe a generator capable of converting ambient vibration energy into electric energy for use in powering intelligent sensor systems. This generator has been tested on a car engine. During the three minute journey, 1.24 km has covered at an average speed of 25km/h. over the period peak power of 3.9mw with an average power of 157microwatt has been produced[6].

9. **Masoud Agah *et al*,** university of Michigan has designed a piezoelectric vibration power generator, which a capable of 1.5microwatt

power with an operating frequency of 400Hz with 1mm long and 50micrometer wide beam[7].

10**. Wen J Li *et al*** proposed a generator based on vibration induced power with a total volume of $1cm^3$ that uses laser micro machined springs is capable of producing 2volt DC with 64Hz input frequency with < 200micrometer input amplitude[8].

Conclusion

It is seen that vibration based electric power generation is more close to passive human power generator than rotary motion based power generator. Also the electromechnical generator generates more power output as compared to piezoelectric or electrostatic. In view of this electromechanical vibration based linear power generator is selected for development.

Electromechanical energy converter:

The electromechanical energy converter is simple in design and generates more power. The basic schematic of the generator is as shown in figure 1. The magnetic mass suspended in the coil is attached to a spring. The mechanical vibration generates relative motion of the magnet inside coil. The voltage is generated due to relative motion of the magnet. This voltage is then converted to DC by rectification and is fed to either to a super capacitor or a rechargeable cell for energy storage.

1.3 Statement of purpose: the main goal of this project is design and produces a battery charger that can charge the battery by harvesting the energy with daily human movements and vibrations. The system is designed such that human daily movements and vibration give energy to an electromagnetic generator and this electromagnetic generator creates electric power to charge up a battery. So with the realization of this project, we can eliminate the requirement of no. of batteries carried with user during long hours because he/she can charge one by small movements of himself/herself .Our main aim to develop a device with a compact and portable design, user friendly and efficient power charging of battery/batteries.

1.4 Project specifications:

Project can be divided into four subprojects. A simplified block diagram is shown below.

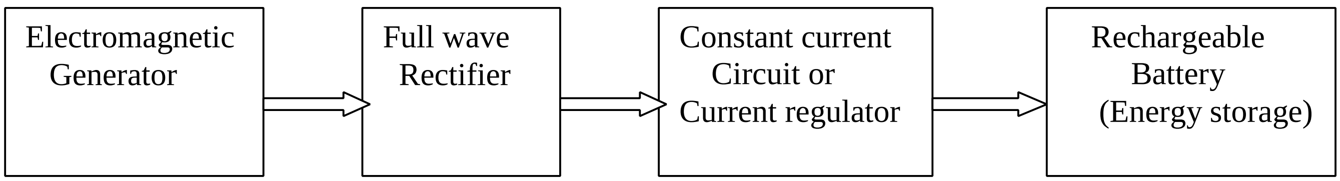

Fig 1.1 Block diagram of Human powered generator

The input of the device is chosen such that a very small human motion can easily produce that much displacement and frequency. The output of the device is set at the voltage needed to charge a small rechargeable battery. So input displacement is chosen 2 to 5mm and input frequency is chosen 2 to 5 Hz. The targeted Output voltage is 3 volt and output power is about to 15mW.

2. A permanent magnet mechanical to electrical transducer:
Generator principle:

As we know that vibration is universal phenomenon and the mechanical vibrations are vibrations that induced by mechanical system. Here we are considering a system that consist a permanent magnet of mass m connected to a one end of a spring. The other end of spring is attached to a rigid housing or frame. If human or any other sources vibrate the housing then permanent magnet moves relative to housing therefore a varying amount of magnetic flux is produced. A coil is coupled to this system such as this coil cuts a varying amount of magnetic flux which in turn induces a voltage on the coil according to faraday's law.

The operation of the generator is based on the famous Faraday's Law, which states that any changes in the magnetic environment of a coil of wire will cause the voltage (or emf) to be induced in the coil. Putting this in equation form

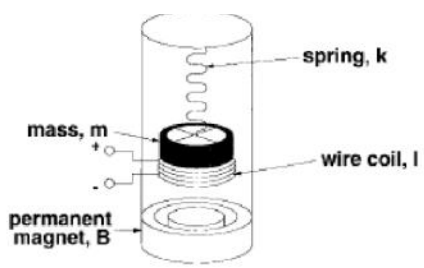

Fig 2.1: General model of electromagnetic generator

$$e = -N\frac{d\phi}{dt}$$

N is no. of turns.

ϕ Magnetic flux.

t is time.

So, our generator is constructed by coiling wires around a tube and has the magnets oscillating within the coil to achieve electromagnetic induction.

However, the actual output voltage from the generator is not going to increase infinitely with the increasing number of turns. This is because the longer wire we used, the higher the resistance will be.

$R = \rho l / A$

R is resistance

l is length of coil turn

A is area

ρ is resistivity

With the increase in the resistance, the voltage drop across the wire will increase according to Ohm's Law, which states that:

$V = I R$

V = voltage,

I = current,

R = Resistance**.**

Hence, the Ohm's Law and the Faraday's Law serve as the guiding rules for the generator design. A compromise between these two is essential for optimal device performance.

3. Mathematical modeling:

The position of magnet (mass) with respect to frame is

X (t)=A sin (wt)

Then

V=dx/dt=Aw cos (wt)

W=2 π f

f is the input frequency of vibration.

The Lagrange function for the entire electromechanical system is kinetic energy – potential energy.

It is given as

$$\lambda = \frac{1}{2} M(\dot{y} + \dot{x})^2 + \frac{1}{2} L \dot{q}^2 + 2\Pi a B_a N x \dot{q} - x^2 / 2K \quad \ldots \text{Eq.1}$$

Where x is position of the magnet with respect to frame

y is position of frame with respect to stationary reference frame

y is the specified time dependent function.

K is the compliance of the spring.(m/kg)

The velocity of mass with respect to reference frame is

$$(\dot{y} + \dot{x})$$

M is the combined mass of the coil and the N turn coil or it can be considered as mass of magnet. (If mass of coil is negligible) If the resistance of coil is R ohms then Rayleigh function becomes

$$f = \frac{1}{2} D \dot{x}^2 + \frac{1}{2} R \dot{q}^2 \ldots \quad \text{Eq.2}$$

With no external mechanical forces the Lagrange function becomes

$$\frac{d}{dt}\left[\frac{\partial \lambda}{\partial \dot{x}}\right] - \frac{\partial \lambda}{\partial \dot{x}} + \frac{\partial f}{\partial \dot{x}} = 0 \; \ldots \quad \text{Eq. 3}$$

From Eq. 1, 2, 3 we have

$$M\ddot{x} + D\dot{x} + \frac{x}{K} - 2\pi\ a\ Ba\ N\dot{q} = -M\ddot{y} \; \ldots \text{Eq.4}$$

The coil is open circuited and the induced voltage is

$$e = \frac{d}{dt}\left[\frac{\partial \lambda}{\partial \dot{q}}\right]\dot{q} = 0 \quad \ldots \text{Eq.5}$$

From this we get

$$e = 2\pi\ a\ Ba\ N\dot{x} \; \ldots \text{Eq.6}$$

This is the open circuit voltage in the coil. And here we consider that spring is in the free position or there is no damping. From Eq. 6 voltage is equal to total length of coil (2π*a*N) times the relative velocity $\dot{x}$ multiplied by air gap field Ba. In actual practice resistance offered by the medium of motion of the body (Damping) affect the system performance. Due to several such factors there is a difference between theoretical and practical output voltages.

Some of them are

- Damping in the motion of system is main parameter that affects the system performance.
- Parasitic damping such as air resistance or hysteresis losses in the suspension, structure and material of the spring and coil also affect the motion of system.
- Spring is not exactly in center of tube. This will also affect output of generator.
- Relative motion of magnet will also affect the response of system.

Now if we consider the viscous damping in the motion then generated voltage is given by

$$e = \frac{(2\pi \; a \; Ba \; N \; M)p^3}{M \; p^2 + D \; p + 1/K} \, y \quad \ldots \text{Eq.7}$$

This can be written as

$$\frac{e}{\dot{y}} = \frac{-k \; p^2}{p/w_n + 2\xi \; p/w_n + 1} \qquad \text{Eq.8}$$

Where

$$k = 2\pi \; a \; Ba \; N \; M \; K \qquad Volt - \sec/m$$

$$w_n{}^2 = \frac{1}{M \; K} \qquad rad/\sec^2 \quad \text{Resonant frequency}$$

$$\xi = \frac{D}{2}\sqrt{\frac{K}{M}} \qquad \text{Damping coefficient}$$

D is the damping in the motion of the system.

M is mass of magnets.

Wn is resonant frequency.

Ba is magnetic flux density of magnets.

N is no. of turns in coil.

The equation 8 can be solved using MATLAB to evaluate the performance of the generator by varying the damping constant.

4. Proposed Model:

4.1 Design procedure:

We have proposed a design on vibration based micro generator that uses a mass (magnet) spring system coupled to a coil to convert mechanical energy to electrical energy by faraday's law of induction.

In this structure we are using two or three rare earth magnets, which are hanged by one end of spring. The other end of the spring is connected to a frame. These magnets are attached with a movable cylindrical plunger .the plunger moves inside the coil which has N turns and length of this coil is l. As the frame is vibrated then magnet will also moves relative to this housing and coil will cuts a varying amount of magnetic flux, which in turn induces a voltage at the coil end.

Data: for three magnet

Length of the coil l: 45mm

Diameter of coil: 17mm

Radius (mean) of coil r=8.5mm

Length of frame: 138mm

Weight of magnet: 88gm (for three magnet)

N=No .of turns (1000, 600,100)

B=magnetic flux density=0.25 T per magnet

K=spring const. =6.6 kg/m or 0.1515 m/kg

Inductance of coil=L

v= velocity of mass (magnet)

We have tested this arrangement for two and three magnets with different no. of coil turns (1000,600,100) input amplitude of 2mm, 3mm and 4 mm at input frequency of 3Hz, 4Hz and 5Hz.

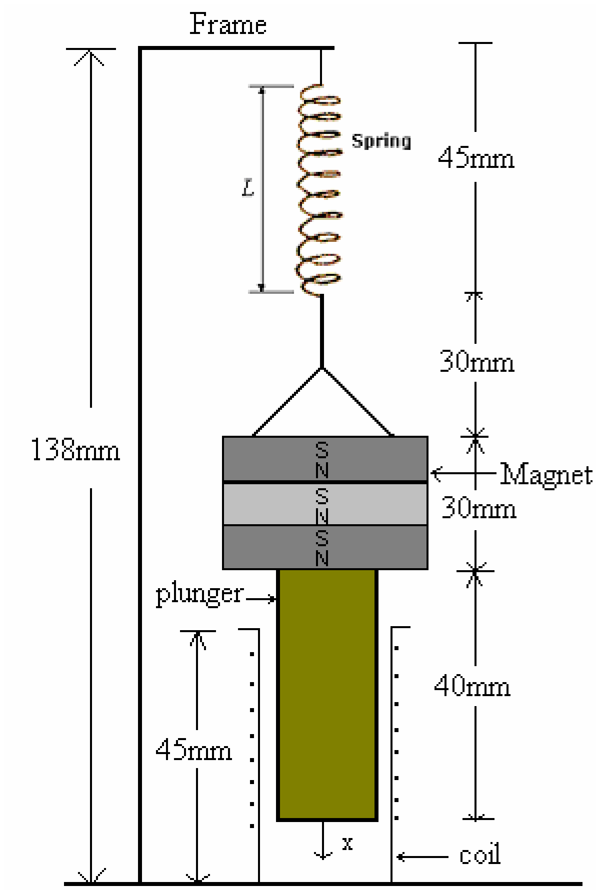

Fig 4.1: structure testing arrangement using three magnets

4.2 Experimental results:

Table1:

Three magnets with no load					**Three magnets with load resi. of 47k**		
I/p Freq.	I/p Amp.	O/p voltage (N=1000)	O/p Voltage (N=600)	O/p voltage (N=100)	O/p voltage (N=1000)	O/p Voltage (N=600)	O/p voltage (N=100)
3	2	0.32	0.28	0.028	0.24	0.20	24
3	3	0.60	0.36	0.050	0.50	0.28	50
3	4	1.2	0.40	0.060	0.80	0.40	70
4	2	1.4	0.4	0.100	1.3	0.32	90
4	3	1.6	0.44	0.120	1.6	0.40	110
4	4	2.0	-----	0.140	2.0	0.50	140
5	2	0.7	0.52	0.060	0.7	0.50	50
5	3	1.3	0.70	0.080	1.2	0.60	70
5	4	1.4	-----	0.120	---		150

Here the waveforms are shown for generation voltage against various frequencies (3HZ, 4HZ, 5HZ) for different amplitude of vibration.

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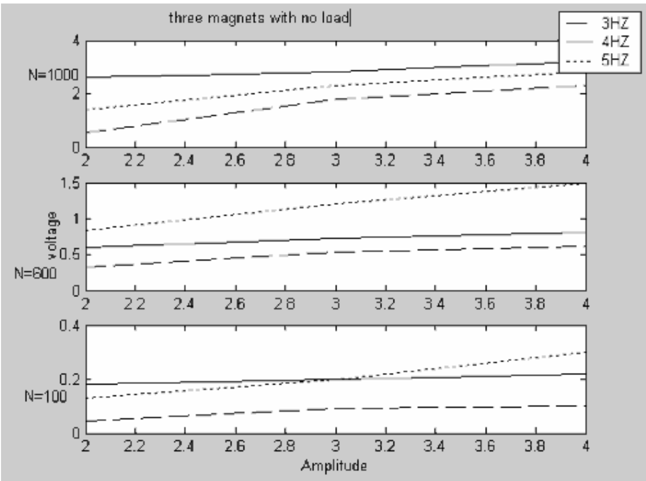


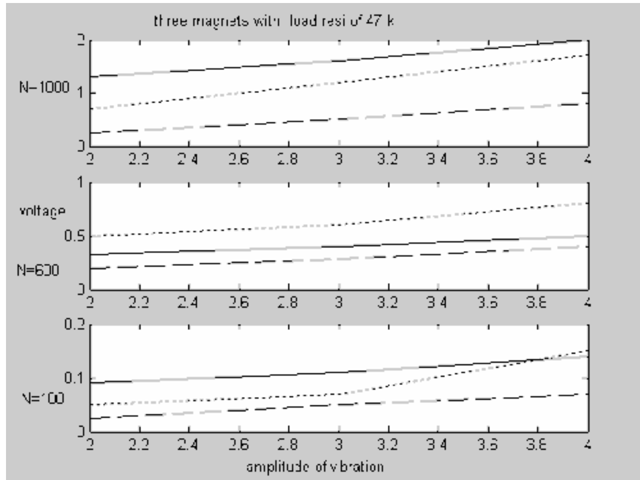
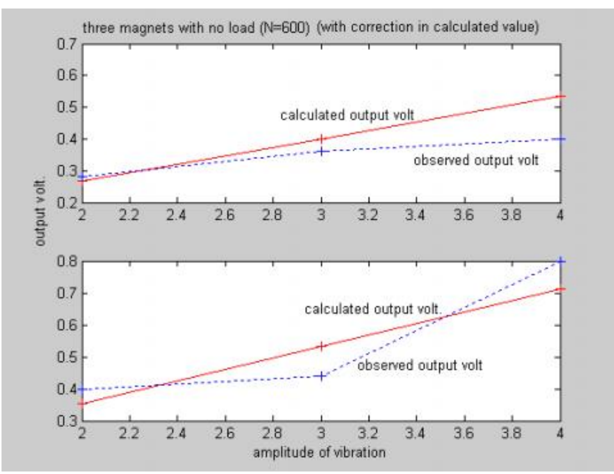


Fig4.2: Three magnets with no load

Fig 4.3:Three magnets with load resi. of 47k

Comparison of output voltage at various frequencies:

N=600 **N=1000**



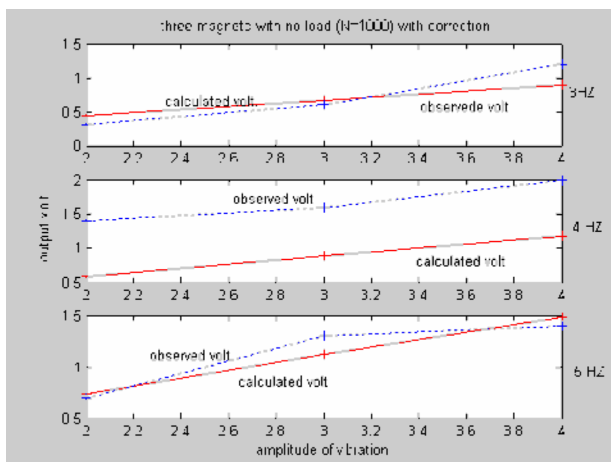


Fig4.4

Fig4.5

4.3 Discussion:

Now we have seen that the maximum output voltage which is obtained in three-magnet arrangement is 2 volt. This is obtained at 4mm and 4HZ. Here we are not considered the damping. If we compare the theoretical and practical results we see that there is considerable difference between these.

All data are obtained by considering free position of spring implies that here we considered that there is no damping in the system. But in actual practice resistance offered by the medium of motion of the body (Damping) affect the system performance. Due to several such factors there are differences in theoretical and practical output voltages.

Some of them are

1. Damping in the motion of system is main parameter that affects the system performance.
2. Parasitic damping such as air resistance or hystersis losses in the suspension, structure and material of the spring and coil also affect the motion of system.
3. Plunger is not exactly in center of coil. This will also affect output of generator.
4. Relative motion of magnet will also affect the response of system.

We have analyzed the human powered micro power generator structure to find the maximum open circuit voltage. Comparing theoretical and practical output voltages has carried out analysis that for an optimized generator damping could be significantly reduced over the design.

As well as we have to modify our structure for getting maximum output voltage. For an example by using other structures of magnets such as circular, bar or cube magnet, we can get more voltage compared to this design.

Other thing is that here we are using a coil that is wound on a plastic material; if we use ceramic or glass then we can get higher output voltage comparison to this design.

5. Improved model of electromagnetic generator:

This structure consists of five main components.

(a) A tube i.e. outer housing for generator.

(b) A spring of magnetic material with spring constant K

(c) No. of small NdFeb magnets of mass m and magnetic field strength Ba.

(d) A copper coil of length λ wound on tube.

(e) A power management circuit for output voltage step-up and energy storing purpose.

Here we are using eight NdFeb magnets of same weight and size and arranged in alternate fashion i.e. North Pole of magnet be connected to south pole of other magnet as we know that opposite poles of magnets attract each other. One end of these magnets is hanged by one end of the spring while other end of the spring is connected to rigid housing or tube. A 2mm diameter groove is cut on the tube in the length of 50mm by leaving 50mm on both upper and bottom sides. A coil of 45-gauge wire is wound on this groove in the length of 50mm groove. Magnets and spring moves inside a tube. When housing is vibrated with amplitude of x then magnet will also vibrate with amplitude of y. Due to this relative amplitude coil cuts a varying amount of magnetic flux, which in turn induces a voltage at the coil end. This structure is shown in figure 1.

Dimensions and Data:

Tube material	=	Perspex
Length of Tube	=	150 mm
Diameter of tube with wall	=	20 mm
Diameter of tube with out wall	=	16 mm

Spring Data:

Length of spring with cork on both sides	=	50 mm
Spring constant	=	52.9 N/m

Magnet Data:

Per magnet length	=	5mm.
Per magnet weight	=	6gm.
Diameter of magnet	=	15 mm
No. of magnets	=	8
Total weight of magnet	=	48 gm.
Magnetic flux Density of magnet	=	0.25 Tesla
Total length of magnetic stack	=	40 mm

Coil Data:

Length of coil	=	50 mm
Gauge of wire	=	45 SWG
No. of turns on the coil	=	2600
Inductance of coil	=	43.2mH
DC resistance of coil	=	715 ohm

The above this arrangement is tested for 2 to 6 Hz frequency at different amplitudes i.e. 2mm, 3mm and 4mm.

5.1 Experimental data:

The electromechnical generator with following parameters is tested on a vibration bench. The bench generates sinusoidal vibration 2 to 6 Hz frequency and 2 mm to 4 mm amplitude

Tube diameter: 20mm with wall

N=2600 turns

L=43.2mH

R=715 ohm

K=52.9 N/m

M=48gm.

Improved Experimental setup:

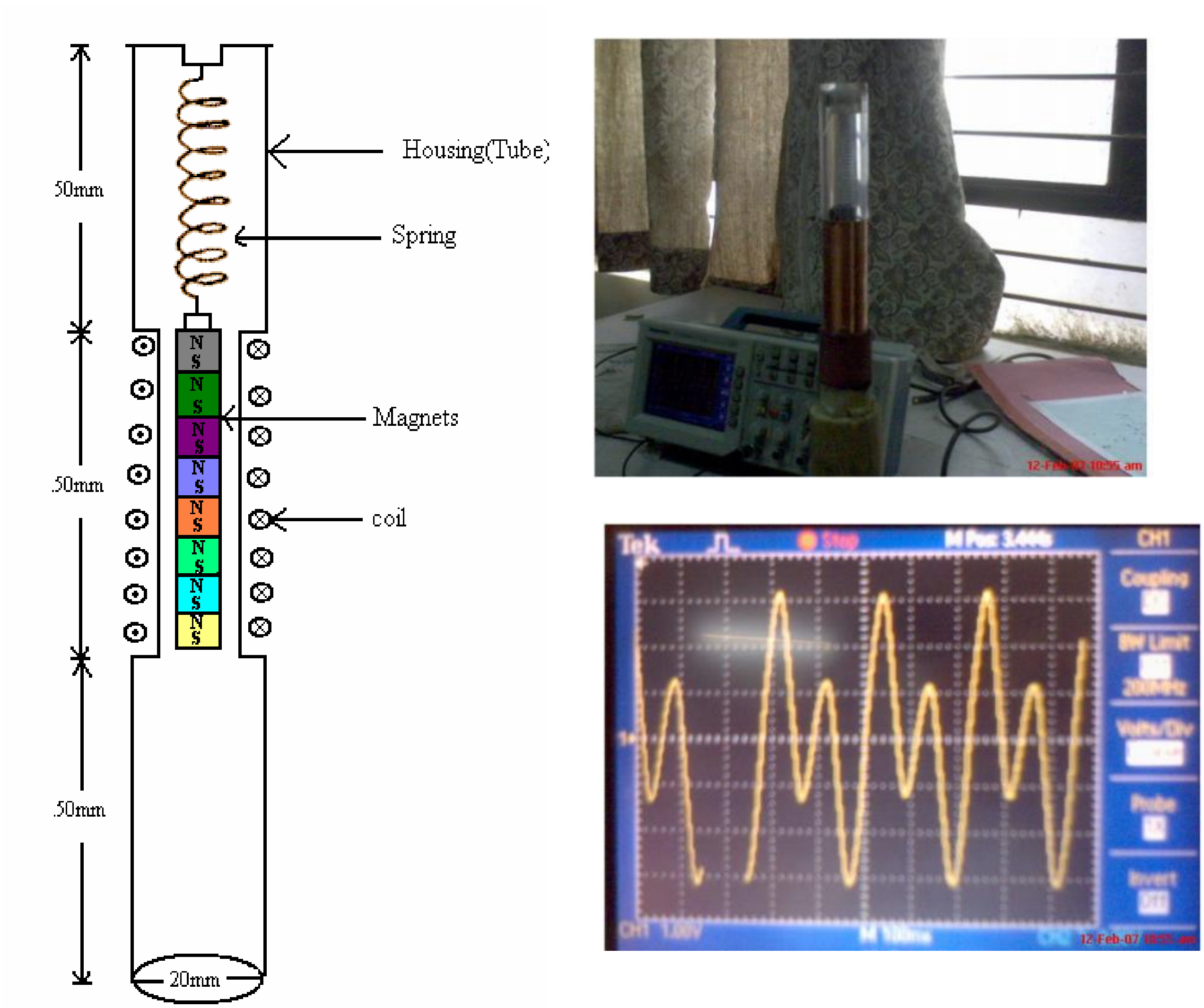


Fig 5.1: Improved experimental setup diagram

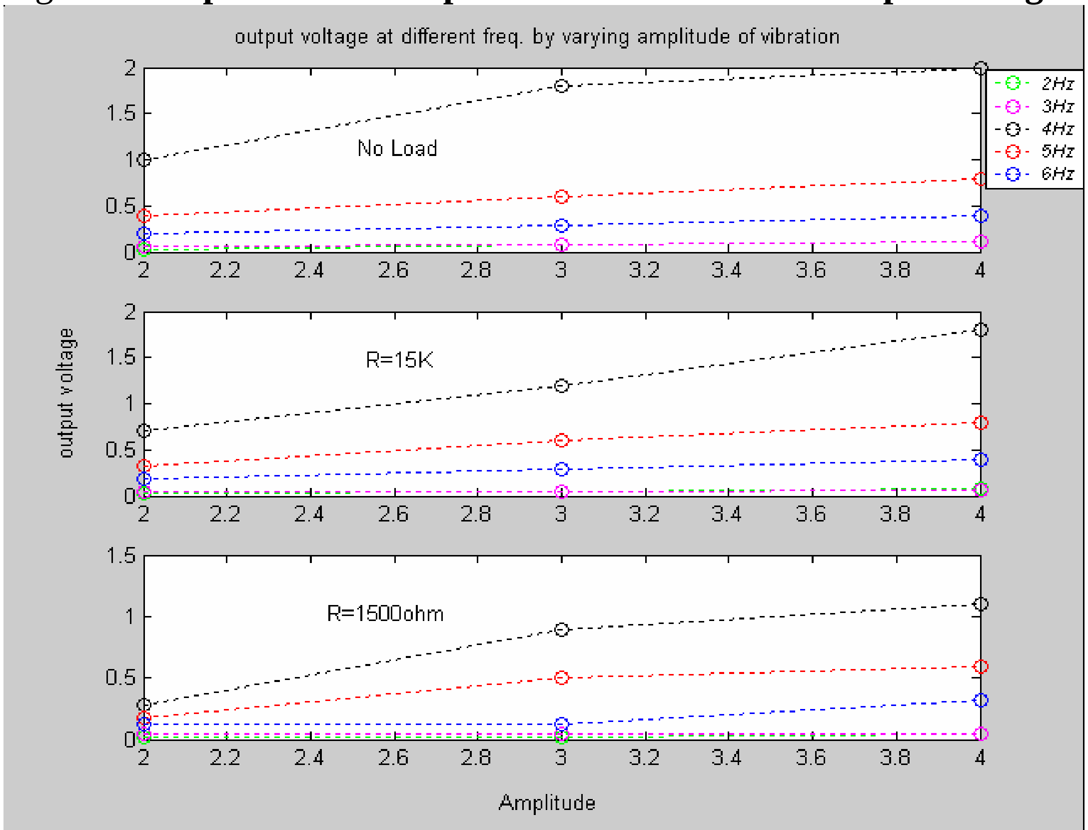
5.2 Experimental results

Experiment No 1: Measurement of output voltage with variable freq and amplitude at different load

Table 2:

Freq. (Hz)	Amp. (mm)	No load **Output voltage (Positive Peak)**	RL=15K **Output voltage (Positive Peak)**	RL=1.5k Output voltage (Positive Peak)
2	2	0.024	0.020	0.014
3	2	0.060	0.036	0.040
4	2	0.8-1.0	0.4-0.7	0.280
5	2	0.24-0.4	0.320	0.180
6	2	0.2	0.190	0.120
2	3	0.07	0.04	0.024
3	3	0.08	0.050	0.040
4	3	1.1	0.8-1.2	0.4-0.9
5	3	0.6	0.6	0.5
6	3	0.28	0.280	0.120
2	4	0.08-0.16	0.080	0.040
3	4	0.04-0.120	0.060	0.050
4	**4**	**1.2-2**	**1.2-1.8**	**0.6-1.0**
5	4	0.8	0.5-0.8	0.3-0.6
6	4	0.4	0.4	0.320

Fig. 5.2: **Graph between amplitude of vibration and output voltage**



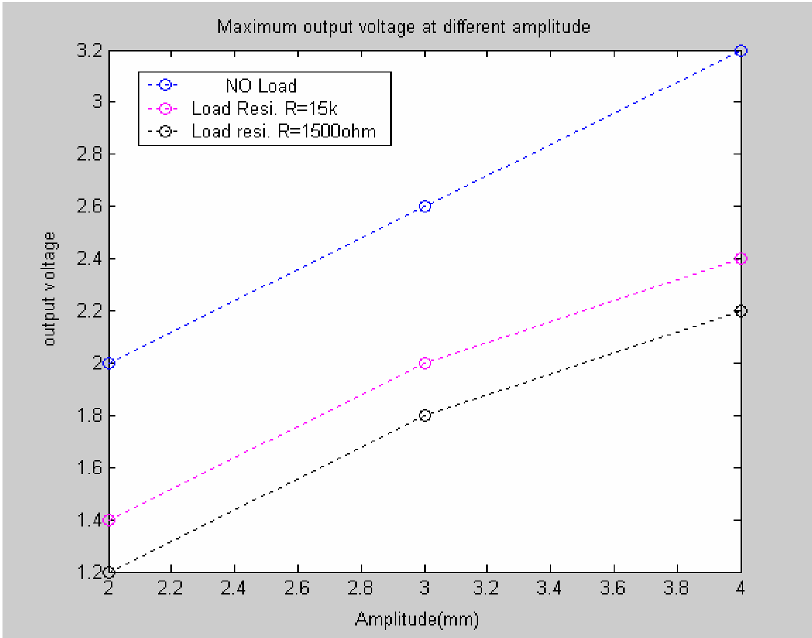
Experiment No 2: Varying the input amplitude of vibrator for maximum o/p voltage

5.3 Maximum output voltage:

Table 3:

Amplitude (mm)	Frequency (Hz)	O/p Volt (No Load)	O/p volt (R=15K)	O/p volt. (R=1500ohm)
2	4.54	2.0	1.4	1.2
3	4.54	2.6	2.0	1.8
4	4.54	3.2	2.4	2.2

Figure5.3**: Variation of maximum output voltage at different amplitude:**

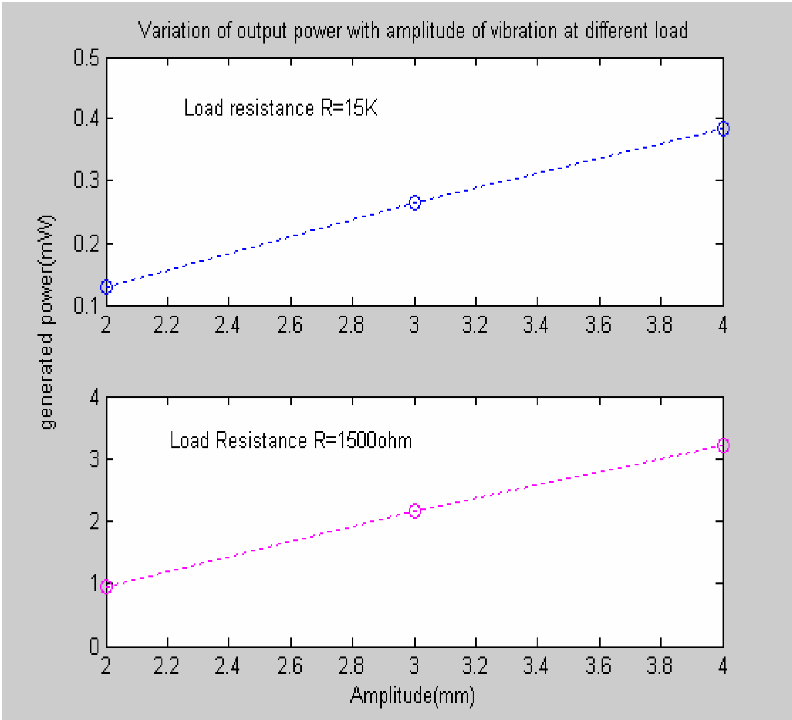


5.4 Calculation for maximum output power

Table 4:

Amplitude (mm)	R_L =1500 ohm		R_L=15000 ohm	
	Output voltage (Volt)	Output power (mW)	Output voltage (volt)	Output power (μW)
2	1.2	0.960	1.4	130.6
3	1.8	2.16	2.0	266.6
4	2.2	3.22	2.4	384.0

Figure 5.4: **Variation of generated output power at different amplitudes of vibration at different load**



5.5 Comparison between experimental and theoretical results:

Table: 5

Amp. (mm)	Experimental Value (Volt)	Theoretical calculated o/p voltage			
		ζ=0.40	ζ=0.50	ζ=0.60	ζ=0.70
		Wn =42rad/sec	Wn =49.1rad/sec	Wn=59.7rad/sec	Wn =235rad/sec
2	2.0	2.54	2.15	1.94	1.86
3	2.6	3.8	3.22	2.91	2.8
4	3.2	5.07	4.3	3.88	3.73

6. Frequency spectrum: Based on above equations (mathematical modeling), output voltage at different damping ratio is calculated frequency spectrum is drawn between input frequency and output voltage.

Frequency spectrum of open circuit output voltages around the resonance frequency of the generator at various damping factors:

Input Frequency=4.5Hz, input amplitude=2mm

Fig6.1:

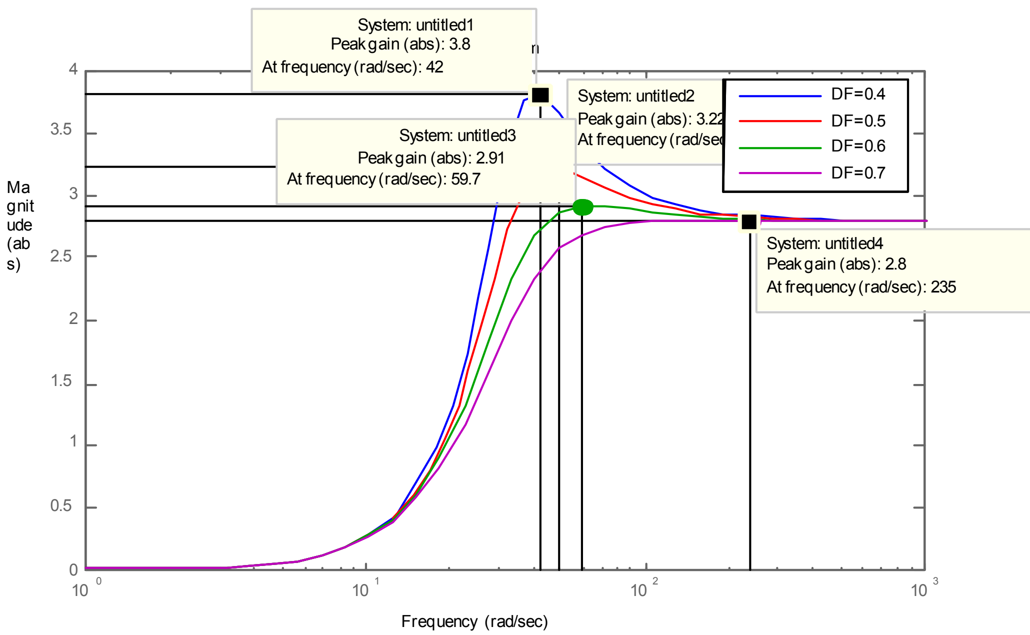


Fig.6.2: Input amplitude 3mm

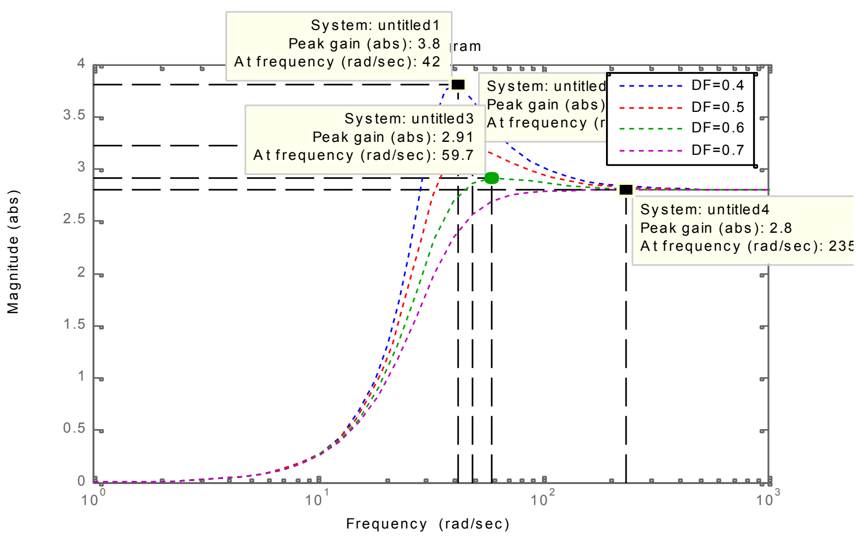
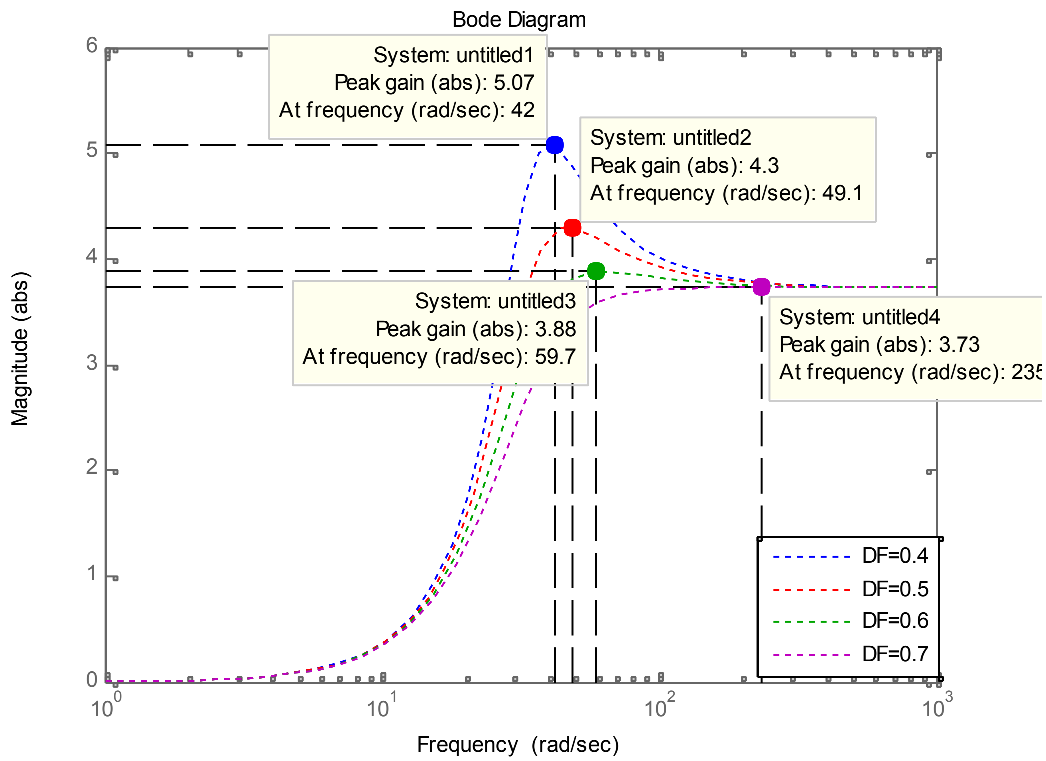


Fig 6.3 Amplitude 4mm:



6.2 Comparison with Published results: Table6

Research Group	Coil (No. of turns)	Magnet mass	Magnet Size (mm)	Wn (Hz)	Amplitude of vibration	Maximum Output voltage (mV)	Generated power (μW)
M.I.T	?	0.50gm	5 x 5 x?	100	?	180	100 *
Sheffield	13	2.4mg	3 x 3 x?	4400	0.1 μm	?	0.3
A.M.L	1500	0.21gm	3 x 3 x 3	64	1.00 mm	2000(DC)	10
Lee	-	0.14 gm			0.015 mm	1290 (AC)	830
CEERI	**2600**	**48 gm**	**D=15mm L=40mm**	**4.54**	**4.00 mm**	**2200 AC**	**3220**

*Denotes with a large impulsive excitation

6.3 Comments on results:

The details of the electromechanical generator developed by AML give most of data except the type of excitation, spring parameters, flux density and damping ratio. This information is very vital for analytical solution and comparison of results.

The procedure for calculating output voltage is repeated with available data from AML for verification of the calculation procedure using MATLAB. The results obtained are as shown in figure 7. It can be seen that the output voltage increases as the damping decreases. The o/p voltage is 2.96 volts AC which is equivalent 2.1 volts DC when the damping ratio of 0.025. The published results indicate 2.0 volts DC without mentioning the damping ratio. If the damping ratio selected by author is 0.025, then our analytical procedure is verified.

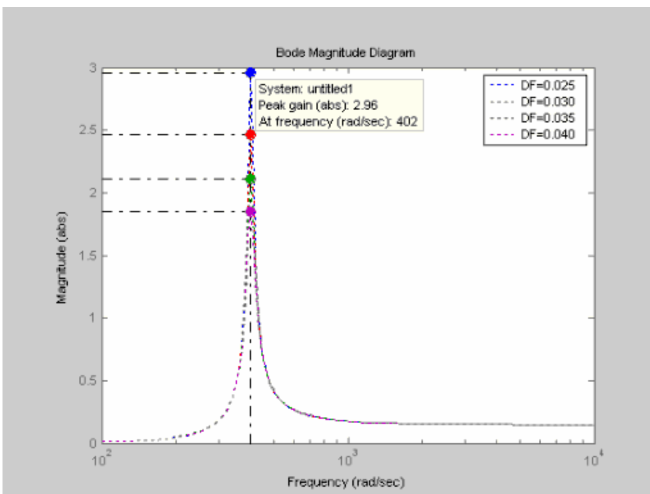


Fig6.4 Frequency spectrum of output voltage similarity

6.4: Experimental results with differential mode windings:
Output voltage with differential mode windings:
Output voltage is stepped up by using two windings in differential mode.
Output voltage with differential mode of windings.
Table6:

Input Freq. (HZ)	Input amplitude (mm)	+ive peak output (Volt)	P-P output (Volt)
2	2	0.060	0.180
3	2	0.180	0.300
4	2	1.0-2.2	2-4.4
2	3	0.140	0.240
3	3	0.320	0.440
4	3	1.8-3.6	3.6-7.2
2	4	0.360	0.600
3	4	0.400	0.600
4	**4**	**4.0-6.2**	**8-12.4**

7. Power management circuit design:

The output power from our generators is distributed among the battery, rectifier circuit and the regulator diodes. Therefore, the efficiency could be increased if we were able to increase the power delivered to the battery by reducing the power dissipated by the rectifier and the regulator circuit. This could be achieved if we were able to find a Schottky diode with smaller forward voltage and lower power consumption.

7.1Full wave rectifier: rectifier is required to convert AC output of the generator into the DC input accepted by the battery. A full wave rectifier with center-tapped transformer is used because it uses only two diodes and has maximum efficiency. Schottky diodes (10BQ015) are used for rectification because of ultra low forward voltage drop and very small footprints on PC boards.

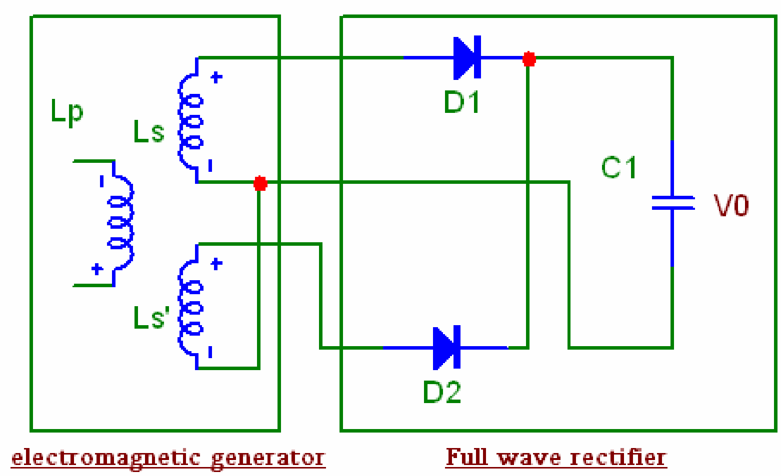


Fig7.1: Module of electromagnetic generator with full wave rectifier

7.2 Battery charging:

7.2.1: **Characteristics of rechargeable batteries:**

A cell is an electro-chemical device capable of supplying the energy that results from an internal chemical reaction to an external electric circuit.

A battery is composed of one or more cells, either parallel or series connected to obtain a required current/voltage capability (batteries comprised of series connected cells are by far the most common).

ESR (Equivalent Series Resistance) is the internal resistance present in any cell that limits the amount of peak current it can deliver.

The Amp-hour capacity of a battery (or cell) is its most important figure of merit: it is defined as the amount of current that a battery can deliver for 1 hour before the battery voltage reaches the end-of-life point.

The "c" rate is a current that is numerically equal to the A-hr rating of the cell. Charge and discharge currents are typically expressed in fractions or multiples of the c rate.

The MPV (mid-point voltage) is the nominal voltage of the cell, and is the voltage that is measured when the battery has discharged 50% of its total energy.

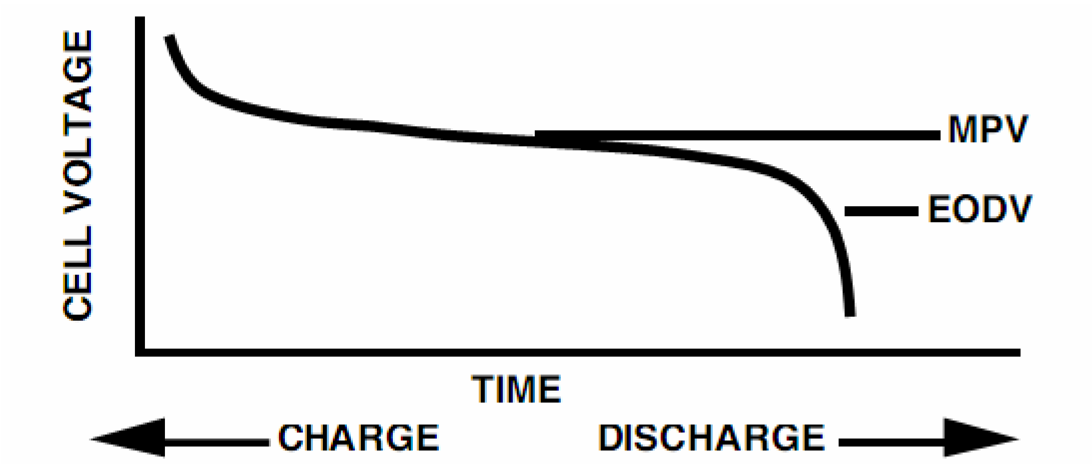
The measured cell voltage at the end of its operating life is called the EODV, which stands for End of Discharge Voltage (some manufacturers refer to this as EOL or End of Life voltage).

The gravimetric energy density of a battery is a measure of how much energy a battery contains in comparison to its weight.

The volumetric energy density of a battery is a measure of how much energy a battery contains in comparison to its volume.

A constant-voltage charger is a circuit that recharges a battery by sourcing only enough current to force the battery voltage to a fixed value.

A constant-current charger is a circuit that charges a battery by sourcing a fixed current into the battery, regardless of battery voltage.



Basic Battery Characteristics

The electrical characteristics of a battery define how it will perform in the circuit, and the physical properties have a large impact on the overall size and weight of the product that it will power.

The key properties and specifications for Ni-Cd, Ni-MH, and Li-Ion will be presented for easy comparison.

Energy Density (By Weight and Volume)

The energy density of a battery is generally expressed in two ways.

The gravimetric energy density of a battery is a measure of how much energy a battery contains in comparison to its weight, and is typically expressed in Watt-hours/kilogram (W-hr/kg).

The volumetric energy density of a battery is a measure of how much energy a battery contains in comparison to its volume, and is typically expressed in Watt-hours/liter (W-hr/l).

The Li-Ion advantage in gravimetric density is clearly the most striking, almost doubling the Ni-Cd and Ni-MH figures.

This means that products powered by Li-Ion cells can be made much lighter without sacrificing run time. Alternately, if the battery weight is kept the same, the run time will double if Li-Ion batteries are used. This fact explains the reason that Li-Ion is quickly displacing Ni-MH in top-of-the-line cellular phones and laptop computers.

CELL TYPE	NI-MH	NI-CD	LI-ION
GRAVIMETRIC DENSITY (W-HR/KG)	55	50	90
VOLUMETRIC DENSITY (W-HR/L)	180	140	210

Cell Voltage/Voltage Stability

The voltage provided to power the load is obviously very important: The Ni-Cd and Ni-MH batteries have a 1.25V nominal cell voltage (their discharge voltages are generally assumed to be identical).

The Ni-Cd/Ni-MH cell voltage is only about one-third of the nominal 3.6V provided by a Li-Ion cell, which means a designer is required to use three series-connected Ni-Cd or Ni-MH cells to equal the voltage of a single Li-Ion cell.

This important difference between the battery types means that Ni-Cd and Ni-MH cells are well suited for use with linear regulators, but Li-Ion batteries require switching converters to obtain good energy conversion efficiency in the power supply.

Peak Current

The maximum current that a battery can deliver is directly dependent on the internal equivalent series resistance (ESR) of the battery.

The current flowing out of the battery must pass through the ESR, which will reduce the battery terminal voltage by an amount equal to the ESR multiplied times the load current

This can result in significant heating within the battery at high rates of discharge.

Charging types:

SLOW CHARGING

"Slow" charge is defined as a charging current that can be safely applied to a battery indefinitely without any kind of monitoring or charge termination method (it is sometimes referred to as trickle charging). A typical Ni-Cd battery will easily tolerate c/10, and some fast-charge Ni-Cd cells will accept up to c/3. Ni-MH cells are not as tolerant of constant charging, as most will not handle a sustained charging current greater than c/40 (although one manufacturer advertises cells that are rated for c/10 trickle charge rate).

It is important to note that Li-Ion cells will not tolerate trickle charging at all after they are fully charged. If current is continuously forced into a fully-charged Li-Ion cell (even a very minute current) the cell will be damaged. For this reason, Li-Ion cells are charged using constant-voltage (C-V) chargers, and not constant-current (C-C) chargers. If a product is designed only for slow (overnight) recharging, a user may have to buy a second battery pack, and keep it on "standby" charge (increasing the amount of money he has to spend).

FAST CHARGING:

"Fast" charge (usually defined as a 1 hour recharge) requires more complex charging circuitry (again raising the system cost) but gives the customer faster charging time (a very attractive selling point).

The typical Ni-Cd or Ni-MH fast charger simply pumps current into the battery, and waits for the battery to signal when its had enough. Because of the possibility of battery damage and user safety hazards, fast-charge systems must be designed to accurately monitor battery parameters like cell temperature and voltage. In addition, most have back up timers for fail-safe cutoff of the high current charge applied to the battery.

Conclusion: All the batteries can be charged under constant current conditions, which is preferred method of charging. Constant current charger is a circuit that charges a battery by sourcing fixed current into the battery regardless of the voltage. Some of the batteries may not be charged by constant potential method because of possibility of thermal runaway.

Thermal runaway: A condition whereby a cell or battery on charge or discharge will destroy itself through internal heat generation caused by high overcharge or over discharge current.

7.2.2 Design of constant current charger:

Using simple transistor configuration can create an excellent current source because no matter what the load resistance or variable input voltage (a range) the collector or load current remains the same i.e. collector current is independent of load in the collector circuit.

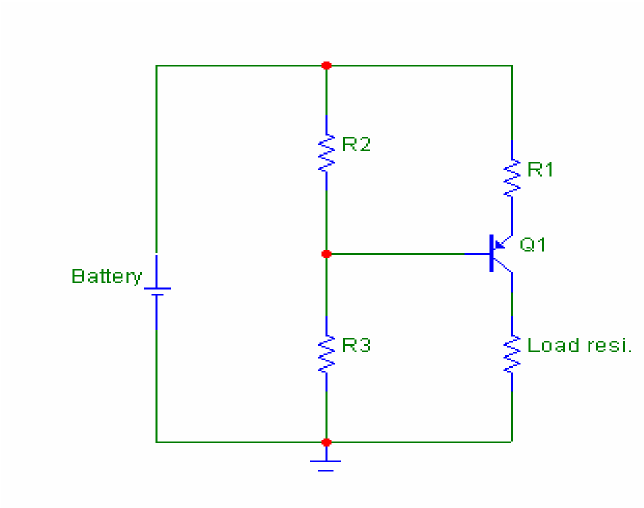


Fig7.2: A simple current source with transistor

Although temperature stability is adequate, output of above circuit is no more stable than the supply so to overcome this effect R2 is replaced by Zener diode.

A stabilized current source can be built using Zener diode because it behaves like a zero resistance battery then the voltage across R1 is almost equal to Zener voltage Vz provided this is much larger than Vbe and therefore the load current is Vz/R1, which is independent of supply voltage.

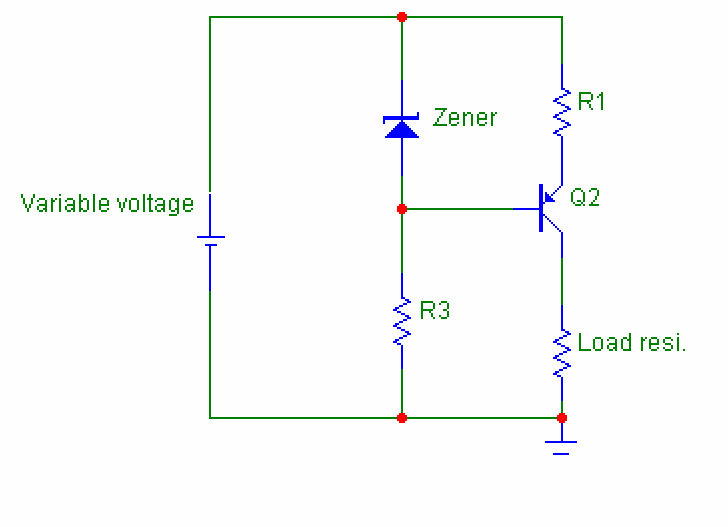


Fig7.3: transistor current source with Zener diode

Now calculating values of R1 and R3 and Vz for 1ma constant current source then following values are obtained.

R1=560ohm

R3=2000ohm

Vz=1.4 volt

Due to unavailability of 1.4 volt Zener, we two silicon diode in series are used.

Complete circuit diagram:

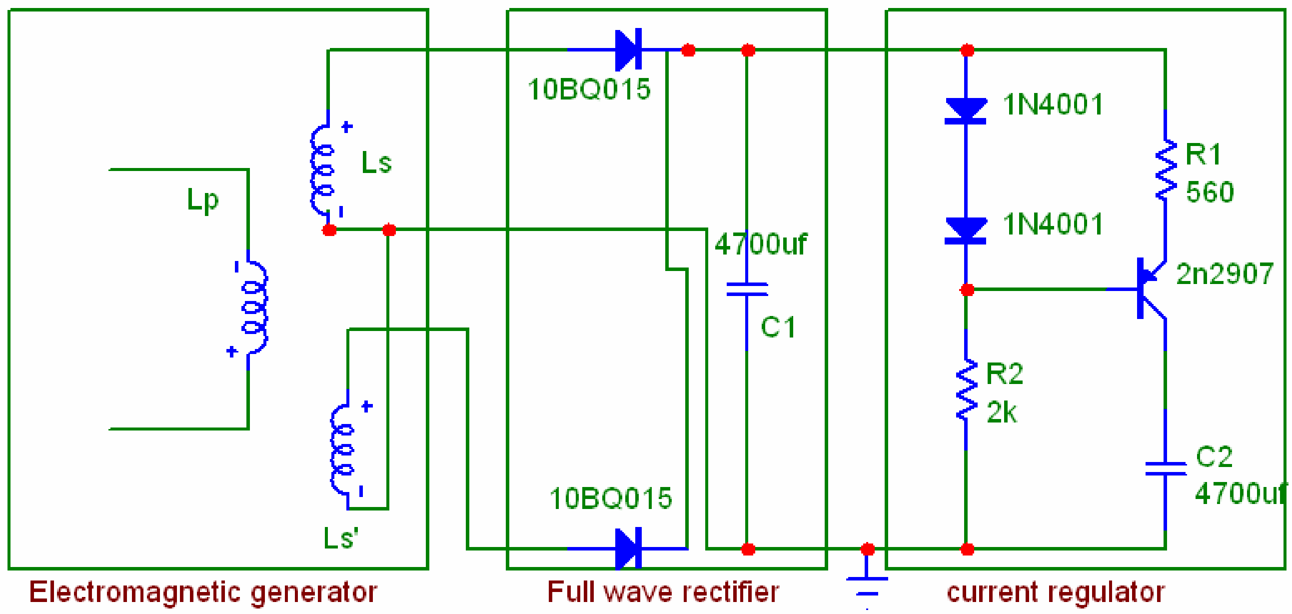


Fig7.4: Human powered micro electric generator

Output waveforms and results:

Output voltage= 4 to 5 volt.

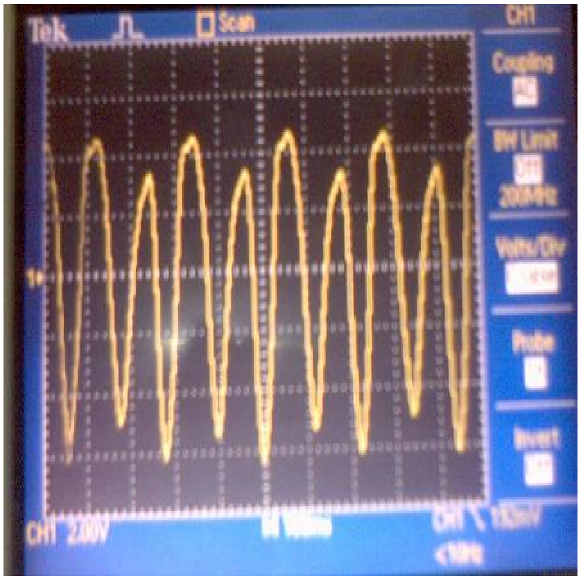


Fig.7.5 Generated ac output waveform at voltage 4mm and 4 Hz

Output voltage=2.58 volt

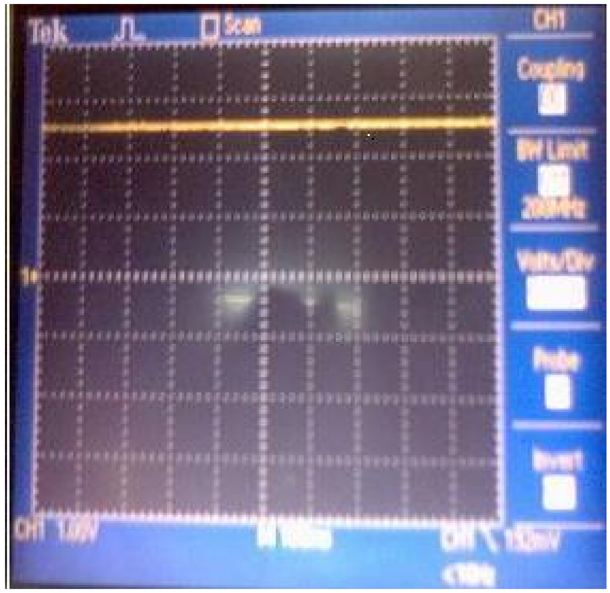


Fig7.6: Rectified output

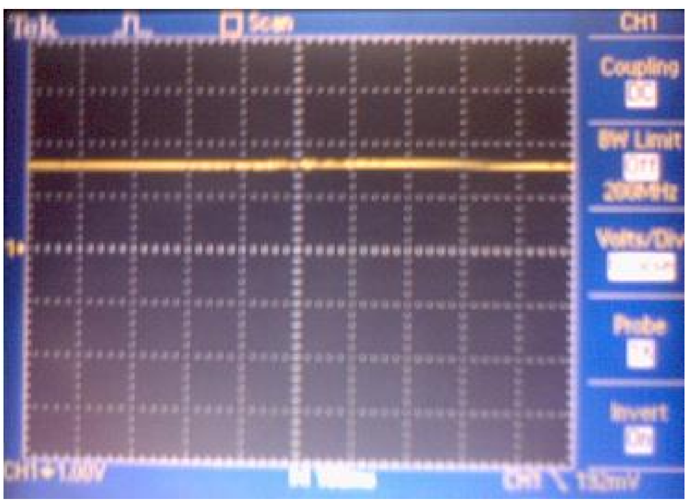


Fig7.7: output voltage in current regulator circuit.

Output voltage at capacitor connected in current regulator circuit is 1.5 volt and current is 1mA.

7.3 Device performance:

Output voltage at input capacitor=2.58volt.

Value of capacitor=4.7mF

Therefore energy input to the current regulator circuit=(1/2) CV^2

=15.40mJ

Now output voltage at output capacitor=1.5 volt

Value of capacitor=4.7mF

Therefore energy stored (output) in this capacitor**=5.2875mJ**

Implies that efficiency can be calculated from input capacitor energy to the output capacitor energy stored.

Efficiency=34.33%

8.Conclusions and Future Work

1. A package structure is fabricated for minimization of damping and better alignment of spring and mass system. This has resulted in higher open circuit voltage.
2. The generator is capable to use 34.33% of stored energy in a capacitor.

Future work:

1. Maximum output power up to 15mW.
2. More efficient power management circuit for step up voltage and energy storing purpose.
3. Study and analysis for damping reduction technique.
4. Testing and performance improvement.

9. Future scope and applications

1. Mobile phone and other low power system
2. Military survival system
3. Robotics system
4. Power source for VLSI system design.
5. for applications where frequent replacement of batteries is not advisable
6. As a power source to integrated electronics system in human and other living species

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