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Design and Modeling of a Novel Micro-Power Generator based on Harvesting Omni-Directional Vibration Energy

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Abstract: In This paper reports on the integration of several technologies to realize, by modeling and design the first two-dimensional (2D) micro power generator which harvesting multi-directional vibration energy from surrounding environmental, which consists of composite cylindrical system with fixed coil and two rounded axial Neodymium permanent magnets.

Index Terms—Energy harvesting, Micro power generator, vibration, Wireless sensor, Electromagnetic.

I. Introduction

NOWADAYS, the concept of energy harvesting has gained a large consideration in the scientific community because of: (1) the continuous decrease in the power consumption of microelectronic devices and systems. Which, becoming so low to allow driving them with the energy stored in a capacitor or in a super-capacitor by a harvester, and (2) Batteries drawbacks represented in (limited life time, bulky, harmful contents, unreliable source where recharging and replacement is needed and expensive wiring system in dense networks) [1]

So, Energy harvesting seems to be a promising and effective solution for delivering power to wireless sensors, WSN, as alternative green power sources that can overcome all previous challenges by Harvesting energy from the application's environment and then converting this energy to electricity using some sort of energy converters which seems to be a promising and the only effective alternative to batteries. Such energy converters are called Micro-Power Generators, MPG's, or Micro-Power Transducers.

Depending on the amount of electrical load power requirements, MPG's can be used to either supply the total power required alone or extend the lifetime of the batteries/ultra-capacitors in case of relatively large power requirements. Vibration based MPG, VBMPG, were one of the most attractive converters due to the availability of the vibration energy in the environment which can be utilized by different transducers (e.g., magnetic, piezoelectric, or electrostatic devices).

Most of the previously reported VBMPG are classified according to their moving element part, coil and magnet shapes, input vibration and /or the device volume. From point of view in this research a new consideration most be taken in classifying VBMPG depending on direction of harvesting energy from surrounding environmental, where the principle of electromagnetic induction for the generation of electrical power from 2D vibration in the environment has been investigated in this paper.

This paper is organized as follows: (1) Energy harvesting as promising power solution is presented, (2) Summary of previous work, (3) General model and design concept, (4) Modeling and analysis for a Novel VBMPG, and (5) Discussion and conclusion.

II. Summary of Previous Work

The reviewed on-going researches are summarized in Table1. Based on literature review of previous works,

Table 1: Summary of Previous Work

Name	Volume cm3	Voltage/Power/ Loading resistance	Resonant frequency
Williams,1996[4]	25 mm3	1 µW/0.1 mW	70 Hz/330 Hz
Neil, 2002 [5]	1 cm3	4.4 Vpp/830 µW/ 1000 Ω	60-110 Hz
Glynne-J, 2004[6]	0.84 cm3	37 µW	322 Hz
	0.84 cm3	180 µW	322 Hz
	3.15 cm3	157 µW	NA
Torah, 2006[7]	<150m m3	52 mVrms/17.8 µW/ 150 Ω	56.6 Hz
Spreemann, 2006[8]	1.5 cm3	0.4-3 mW	30-80 Hz
E. Koukharenko , 2006[9]	100 mm3	0.7 V/ 104 nW/2 kΩ	1.165 kHz
Beeby, 2007[10]	0.15 cm3	428 mVrms/ 46 µW/4 kΩ	52 Hz
Wang, 2007[11]	0.18 mm3	60 mVpp	121.25 Hz
Saha, 2008[12]	12.48 cm3	14.55 µW/ 7.3 kΩ	8 Hz
	12.48 cm3	0.3 mW	2 Hz
	12.48 cm3	1.86 mW	2.75 Hz
	12.48 cm3	0.95 mW	NA
	12.48 cm3	2.46 mW	NA
Sari, 2008[13]	-	10 mV/ 0.4 µW	4.2-5 kHz
Zhu, 2010[14]	-	61.6-156.6 µW	67.6-98 Hz
Sari, 2010[15]	-	0.57-mV / 0.25-nW	70-150 Hz
Rahimi,2012[16]	16 cm3	1.46 V DC / 54 µW	8Hz

III. General model and design concept

A novel design eliminate constrains of previous rods where it allow vibration of model in 2D avoiding miss alignment problems.

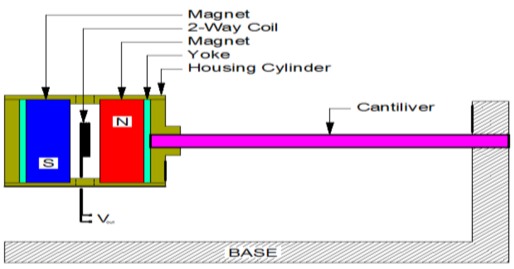

Figure 1: A Novel MPG Model

It consists of:

1. Cylindrical Cantilever rod made of non magnetic material "copper" to avoid distortion of magnetic field with adjustable length to wide range of band used in as shown in figure (3),
2. Transduction Mechanism

2-axial permanent magnet discs with dedicated volume using self separator of housing cylinder to get a needed a certain flux density was one of parameter.

3. Coil Configuration

A greater output can be achieved from the electromagnetic micro generator by increasing the number of coil windings and reducing the impedance of the coil, but with in magnets configuration

A 2-way fixed copper coil was the most possible solution to accumulate produced MMF in Coil sides as shown in figure (5)

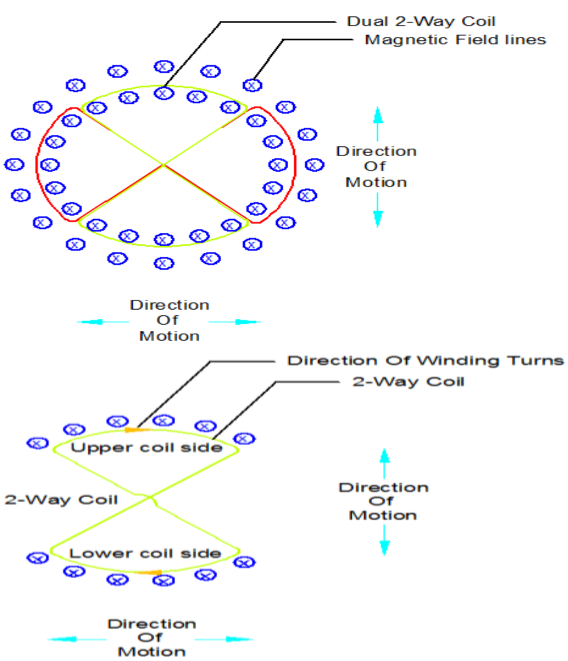

Figure 2: Two-Way Coil Configuration

IV. 2D physical model description

This section presents the first 2D electromagnetic VBMPG developed in order to verify the analytical model of the VBEMPG presented in the previous section.

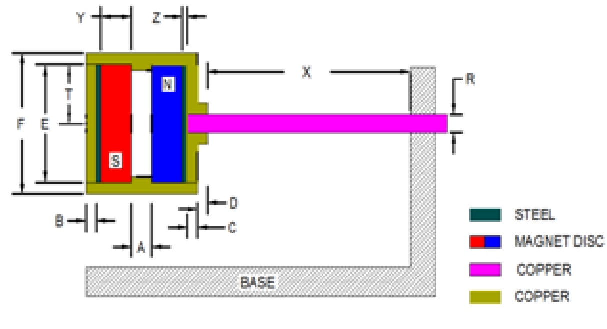

Figure 8: Dimensional detailed model section

The mechanical damping coefficient, b_m, is calculated proportional to verified 1D model according to stated experimental result at [2]. Finally, the simulation results are discussed.

The first 2D-MPG consists of composite cylindrical system with fixed coil and two rounded axial Neodymium permanent magnets.

Cylindrical rod "moving element" is used to get a linear movement with adjustable length to control both the displacement and the amount of generated power.

Figure (8). Show a MPG side view of the model consisting of a moving composite cylindrical mass and a fixed coil supported by base. The rounded coil has an average radius of 0.5cm which made of 24 Turns of 120μm copper wire diameter with filling ratio 60%. A system of two rounded axial Neodymium permanent magnets, 20mm diameter and 7.2mm thickness each, with 4mm air gap.

Table 2: Model Parameter

Parameter	Definition	Value
X	Cantilever length	4 cm
B, C	Holding cylinder base length	2 mm
D	Tip cantilever length	2 mm
R	Cantilever radius	3 mm
E	Housing cylinder base radius	2 mm
Z	Steel yoke length	1 mm
E	Steel yoke diameter	2 cm
T	Permanent magnet disc radius	1 cm
F	Housing cylinder outer diameter	2.4 cm
A	Air gap between magnets	4mm

ρc	Copper density	8912 Kg/m3
ρst	Steel density	7800 Kg/m3
ρm	magnet density	7400 Kg/m3
Ec	Copper Young's modulus	197 × 109 N/m
Est	steel Young's modulus	210 × 109 N/m
Em	magnet Young's modulus	150 × 109 N/m

An external steel yoke is used to increase the flux density in the air gap by providing an easy return path for the magnetic field. The internal resistance of the coil was calculated at 1.13 Ohm with effective length ℓ = 75.36Cm. The dimensions and material properties of the model are listed in Table 2.

V. Magnetic field analysis

Figure 9 shows analysis using ANSYS. a non uniform magnetic field distribution is shown, with maximum flux density in the air gap equal to 0.737 Tesla, The material of the permanent magnet used in the simulation was Neodymium-Iron-Born with axial flux of 1.2 Tesla and coercive force of 950 KA/m. Silicon-steel was used as the soft magnetic material and its B-H curve was borrowed from ANSYS's material library.

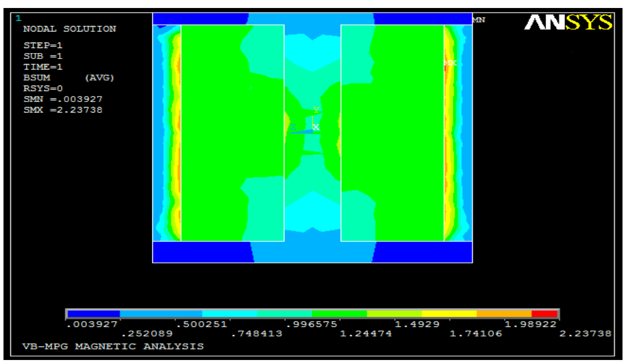

Figure 9: Magnetic Field Simulation result

VI. Mechanical analysis

The total effective mass calculated for the system is 76.09 gram and the effective cantilever length can be calculated at 5.48cm, as shown in figure (10). Where m_1 is the total mass of the housing cylinder with magnet and yoke (proof mass), and m_2 is the mass of both the tip cantilever and cantilever rod of length 4.7cm.

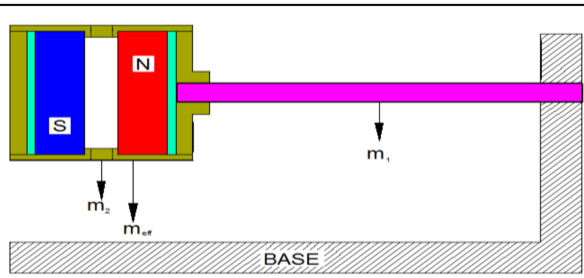

Figure 10: Mass Distribution Approximation

Assuming small deflection analysis, the spring constant can be calculated using two assumptions: (1) the housing cylinder as rigid body with no deflection with effective mass m_2 at the end of cantilever rod. (2) Neglecting the mass of cantilever as $m_1 << m_2$

And so,

$$m_{eff} = m_2$$

Calculating stiffness of model using general formula [3]

$$\kappa\lambda \quad K = \frac{3E\,I}{L^3} \qquad (1)$$

Where I is the moment of inertia for the cantilever

$$I = \frac{\pi R^4}{4} \qquad (2)$$

The stiffness of system is around 245254.2 N/m, using the total effective mass and the spring constant, the undamped resonance frequency can be calculated to be 270Hz.

VII. Simulation result

Modal analysis is used to study free vibration characteristics of model to select the desired mode of vibration, damped 3D modal analysis was done using the FEA package; ANSYS, as shown at figures (11, 12). And the simulation result is shown in table (3) for extracted first 2 modes of modal analyses.

Table 3: Modes of Operation

Modes	Frequency (Hz)
First	272.42
Second	272.67

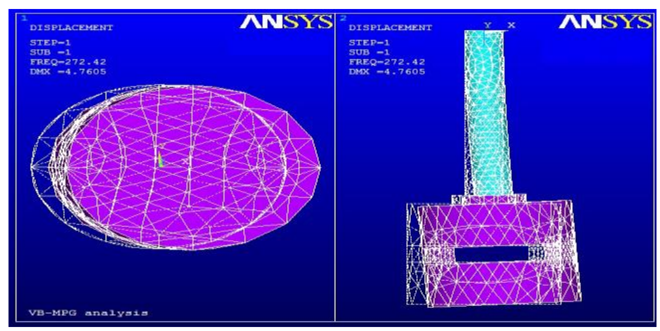

Figure 11: Modal Analysis of 1st. Mode

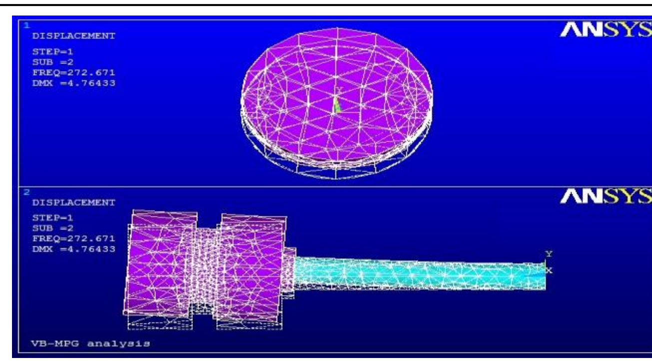

Figure 12: Modal Analysis of 2nd. Mode

Harmonic analysis is done by using FEA package to determine the resonance frequency for model "where maximum power generated "around different mode extracted before as shown at figure (13, 14) by applying acceleration at X and Y direction equal to 12m/sec2.

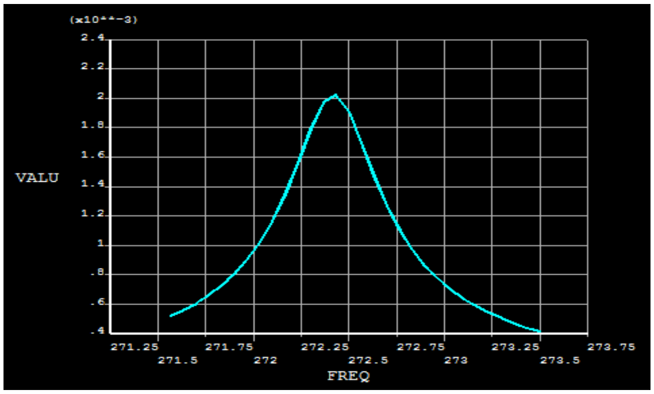

Figure 13: Y-Displacement at A_Y=12m/sec2, A_X=0m/sec2

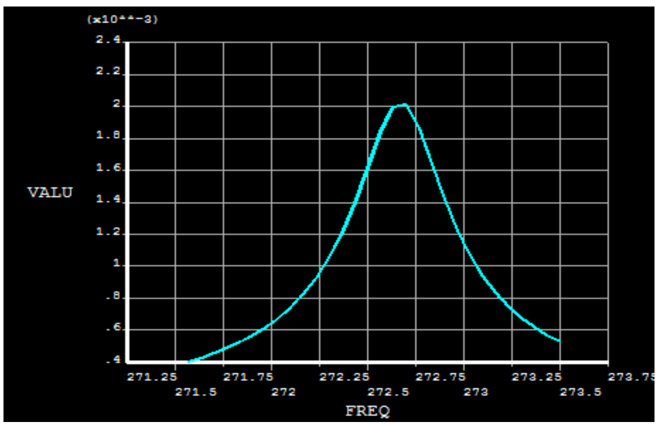

Figure 14: X-Displacement at A_X =12m/sec2, A_Y=0m/sec2

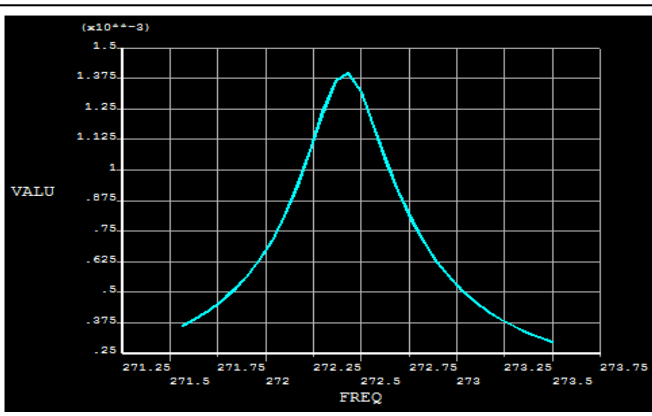

Figure 15: X- Displacement at Ax =Ay=12/√2 m/sec2

Deflection in (X-Y) axis determined by applying acceleration at X and Y-direction equal to Ax=Ay=12/√2 m/sec2 as shown at figure (15, 16).

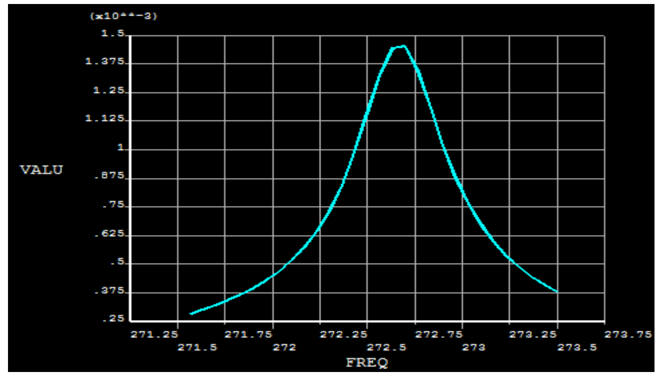

Figure 16: Y- Displacement at Ax =Ay=12/√2 m/sec2

Simulation result show good agreement with theoretical predicted result where applying acceleration in x and y with same value give nearly same deflection in between at with small variation due to different damping coefficient in 2-axis due to model design.

VIII. Conclusion

A novel micro power generator vibration based confirms a new approach for harvesting vibration energy in Omni-directions increasing modes of operation with verity application and overcome other restricted previous model.

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