Dinesh R. Palikhel, Tyrus A. McCarty* and Jagdish P. Sharma

Nano-Mixture Coating and Geometrical Configuration Impact on Cantilever Based Piezoelectric Energy Harvesting System

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Abstract: Vibrational energy from intermodal transport system can be recovered through the application of piezoelectric energy harvesting system. The intermodal vibration sources are passenger cars and freight trucks moving on streets and highways, trains moving on railway tracks and planes moving on airport runways. However, the primary limiting factor of the application of the piezoelectric energy harvesting system has been the insignificant power output for power storage or to directly power electrical device. A special nano-mixture coating is developed to enhance the energy harvesting capability of the conventional piezoelectric material. This research investigates the impact of the nano-mixture coating on the power output. The experimental results of the nano-mixture coated system show substantial and explicit improvement on the power output. Alternative geometrical designs, trapezoidal and triangular are explored in anticipation for improved power output. But the rectangular energy harvester demonstrates better power harvesting capability. The results presented in this paper show the potential of the nano-mixture coating in power harvesting from intermodal transport system.

Keywords: cantilever, energy, experimental, geometry, nano-mixture coating, piezoelectric, PZT, ZnO

Introduction

Piezoelectric materials have been researched for energy harvesting and have gained considerable interest in the area of energy harvesting system. There are multiple systems to extract ambient energy, piezoelectric system being one of the major interest because of its high power densities, broad voltage output spectrum and its application convenience over other systems (Cook-Chennault, Thambi, and Sastry 2008). Piezoelectric system works on the principle of conversion of mechanical energy to electric energy due to the induced stress in the piezoelectric material. Vibration, pressure or applied load are the sources of the induced stress which creates piezoelectric excitation. The major attraction to the research on energy harvesting from vibration sources is that these sources can virtually be found everywhere in the environment (Mateu and Moll 2005a). Lead zirconium titanate (PZT) is a piezoceramic material with proficient piezoelectric effect and it is one of the most widely researched piezoelectric materials in the area of vibrational energy harvesting (Mateu and Moll 2005b).

There is a considerable opportunity to tap existing source of energy being lost to the environment in the form of vibration. One of the promising source of vibration is intermodal transport systems. These vibrations result from intermodal transport systems such as passenger cars and freight trucks moving on streets and highways, trains moving on railway tracks, and planes moving on airport runways. Energy harvesting systems consisting of PZT as the primary energy harvesting component can be incorporated into the intermodal transport systems to recover vibrational energy. Integrating piezoelectric energy harvesting system into intermodal transport system for recovering energy from these lost vibrations will have considerable economic and environmental impact on the intermodal transport system. Benefits of this integration includes numerous application outcome such as powering intermodal transport lights and signals and monitoring intermodal transport structure conditions.

The major and fundamental limiting factor of the piezoelectric energy harvesting system is its low power output (Sodano et al. 2002). It is one of the enticing area of research needing more scientific work and effort. In terms of structural shape optimization of the piezoelectric energy output from the system, numerous work with various approach has been done (Baker, Roundy, and Wright 2005; Benasciutti et al. 2010; Rosa and Marqui 2014; Roundy et al. 2005; Shafer, Bryant, and Garcia 2012). Shafer, Bryant, and Garcia (2012) developed

***Corresponding author: Tyrus A. McCarty,** Department of Mechanical Engineering,University of Mississippi, Oxford, MS 38677, USA, E-mail: mccarty@olemiss.edu
Dinesh R. Palikhel: E-mail: drpalikh@go.olemiss.edu, **Jagdish P. Sharma:** E-mail: jsharma@olemiss.edu, Department of Mechanical Engineering,University of Mississippi, Oxford, MS 38677, USA

piezoelectric energy harvester and optimized the thickness of the piezoelectric layers of a beam relative to the total beam thickness for maximum power output. They came up with a single algebraic expression for the power output from piezoelectric energy harvesting system. Design requirement variables can be plugged into the expression to develop piezoelectric energy harvesting beam design and optimize the power output quickly without requiring optimization algorithms. Baker, Roundy, and Wright (2005) investigated different geometry of vibration energy scavenger for optimizing the power density of the system. Their design of the piezoelectric power harvester using a harmonically matched trapezoidal geometry improved the uniformity of strain distribution increasing the power output per unit volume by 30 % as compared to rectangular geometry. Roundy et al. (2005) explored the alternative design of the mechanical structures of PZT energy harvester to maximize the power output. Their design approach is based on preventing the overstrain of PZT and distributing the strain uniformly in the energy harvester. They found that trapezoidal design is more efficient than rectangular and it can produce double the energy as compared to rectangular output. Benasciutti et al. (2010) came up with trapezoidal and reverse trapezoidal shapes as alternative to traditional rectangular shape for optimizing the specific power generation. Their FEM model shows that their reverse trapezoidal configuration generates better specific power generation than trapezoidal and rectangular configurations. Rosa and Marqui (2014) addressed varying cross-sectional area to get efficient trapezoidal and reverse trapezoidal shape of the bimorph piezoelectric harvester while considering the optimum load resistance.

Structural shape of the energy harvester other than rectangular or trapezoidal cantilever plate has also been investigated (Erturk, Renno, and Inman 2009; Kim, Clark, and Wang 2005; Mossi et al. 2005). Kim, Clark, and Wang (2005) explored clamped circular unimorph piezoelectric plate design as the energy harvesting structure. Curved unimorph prestressed bender has been studied to investigate the impact of geometry on energy harvesting (Mossi et al. 2005). Erturk, Renno, and Inman (2009) investigated L-shaped beam-mass as a piezoelectric energy harvesting structure theoretically with a distributed parameter model to examine its coupled electromechanical behavior. To compare different approaches and design parameters of vibrational energy harvester, a general theory was developed by Roundy (2005).

Despite numerous approaches and methods to optimize the power output from piezoelectric energy harvesting system, the limiting factor for its application in real world has been the insufficient power output. This is the motivation behind various ongoing research works in this area. In this work, we introduce and explore a novel idea of integrating nano-mixture coating into traditional PZT energy harvester. Thus, this experimental study focus on the impact of nano-mixture coating on PZT energy harvester in terms of its power harvesting capability. Conventional rectangular cantilever structure is designed, constructed and investigated as the piezoelectric energy harvester. Trapezoidal and triangular configurations are then experimented and their comparison with rectangular system is done.

Experimental Procedure and Setup

PZT Composite and Nano-Mixture Constituents for Coating

PZT is the electromechanical and major energy harvesting element of the piezoelectric energy harvesting system of this work. PZT composite investigated in this work is the commercially available component manufactured by Murata Manufacture Co., Ltd (Part no: 7BB-27-4L0). The structure of the energy harvesting system on which PZT components are attached is the steel cantilever beam with thickness of 0.51 mm which made up of 17–7 annealed stainless steel sheet. Zinc oxide (ZnO) is a piezoelectric material which is the functioning constituent of the nano-mixture coating for power generation enhancement. The constituents of nano-mixture coating are ZnO, ferrofluid and epoxy binder. Based on the previous study by University of Mississippi researcher (Sharma 2012), it was discovered that the optimum percentage of ZnO in the nano-mixture coating for the maximum energy harvesting capability of the system is 40 %. Thus, composition of the constituents considered for this study are 40 % ZnO, 58 % ferrofluid and 2 % epoxy binder. Schematic of the PZT composite with nano-mixture coating is shown in Figure 1.

ZnO in the form of nano-powder, < 100 nm particle size obtained from Sigma-Aldrich Inc. (Product number: 544,906) is used for the formulation of nano-mixture coating. Ferrofluid (Supplier: Amazing Magnets Inc., Trade name: EFH1) has the composition of the mixture of magnetite (3–15 % by volume), oil soluble dispersant (6–30 % by volume) and carrier liquid (55–91 % by volume). The epoxy (Supplier: Epoxy Technology Inc., Product name: E4110-LV) applied as an adhesion agent is electrically conductive and silver-filled. The epoxy helps the cured

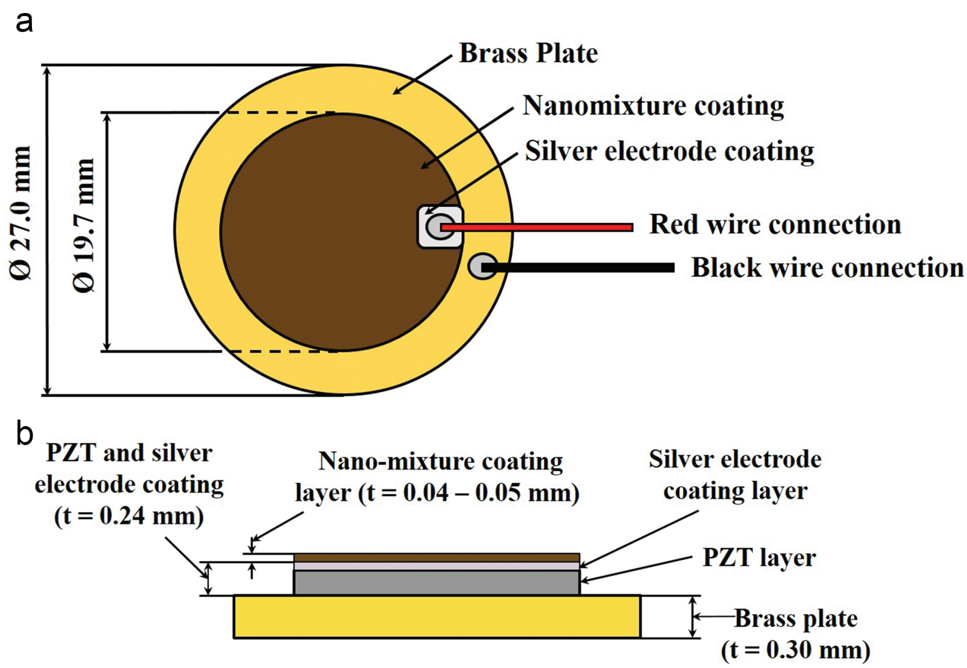

Figure 1: Schematic of nano-coated PZT composite. (A) Top view. (B) Side view.

nano-mixture coating to adhere firmly into the PZT composite in the course of the experiment. It also works as a binding agent thereby making the nano-mixture coating a piezoelectric layer integral assembly and helps in the positional stability of the ZnO nanoparticles and ferrofluid constituents in the cured nano-mixture coating. The electrical conductivity of epoxy also helps in the flow of the piezoelectric charge developed in the ZnO nanoparticles to the silver electrode.

Nano-Coated PZT Composite Preparation

To create the 2 gm of nano-mixture coating, 0.8 gm of ZnO (40 % by weight), 1.16 gm of Ferrofluid (58 % by weight) and 0.04 gm of epoxy resin (2 % by weight) is measured in Mettler Toledo AG245 analytical balance. These three components are mixed vigorously in a centrifuge tube manually with the help of 1.5 mm thick aluminum rod. The nano-mixture coating is then applied on to the silver electrode coating of the PZT composite. It is applied in such a way that the nano-mixture coating does not come in contact with brass plate electrode which otherwise cause short circuit and the output signal from PZT composite to be disturbed or lost during due to short circuit between the silver electrode and brass electrode of the PZT composite. The recommended cure for the epoxy in the nano-mixture coating is 150 ºC for 1 hour. To avoid any possible adverse effect on the PZT composite and nano-mixture coating due to exposure to high temperature of 150 ºC, alternative curing method is implemented. The nano-mixture coating is cured by placing the nano-coated PZT composite inside desiccator for 3 days at ambient temperature condition.

Cantilever Structure Geometry

For the real world application of the energy harvesting system in intermodal transportation system and wireless sensor network system, multiple single nano-coated piezoelectric component must be incorporated into the integrated system for the analysis and implementation of the energy harvesting systems. This work incorporates 3 PZT into the energy harvester and investigate this multi PZT energy harvesting system. For the multi PZT energy harvesting system, alternative geometrical design of the cantilever beam structure is explored and analyzed with the anticipation of the optimized power output. Optimization process for energy harvesting capability is done for the three geometrical structures of multi nano-coated PZT composite system. The main focus is given to the power output trend and the maximum power output at the considered frequency range. Thus, the non-coated PZT composite cantilever system and nano-coated composite cantilever system is constructed and investigated for the power output in the three geometrical structures, rectangular, trapezoidal and triangular. The conceptual difference between the geometrical design in the literature (Baker, Roundy, and Wright 2005; Benasciutti et al. 2010) and this work is the shape of the PZT and the cantilever beam. The studies in the literature consider the change in geometry of entire PZT in cantilever beam, whereas in this the work considers the change in geometry of the steel cantilever beam only, while the PZT shape remains circular in all the cases.

The design schematic with top view dimensions and actual picture of the constructed rectangular system is depicted in Figure 2. Length and width of the rectangular energy harvester is designed in such a way that maximum number of 6 PZT composites can be fitted in longitudinal (axial) direction and 3 PZT composites in transverse direction, thus allocating space for total number of 18 composites on the top surface area of the cantilever beam. It should be noted that bottom surface area can also be used for additional 18 PZTs to optimally utilize the whole cantilever beam for piezoelectric energy harvesting. Although the maximum number of PZTs that can be attached to the cantilever beam is 18 on the top and 18 on the bottom, the total number of PZTs that is applied and studied in this work is 3 as shown in the Figure 2. The maximum number of PZTs is conceptual and considered only for determining the length and width of the rectangular cantilever beam. The cured nano-coated PZT composite is mounted on a standard stainless steel cantilever beam through a taping procedure which uses a double layer of two sided clear 3 M Scotch tape. The cantilever beam with 3 nano-coated PZT composites, the energy harvesting component of the experimental procedure is

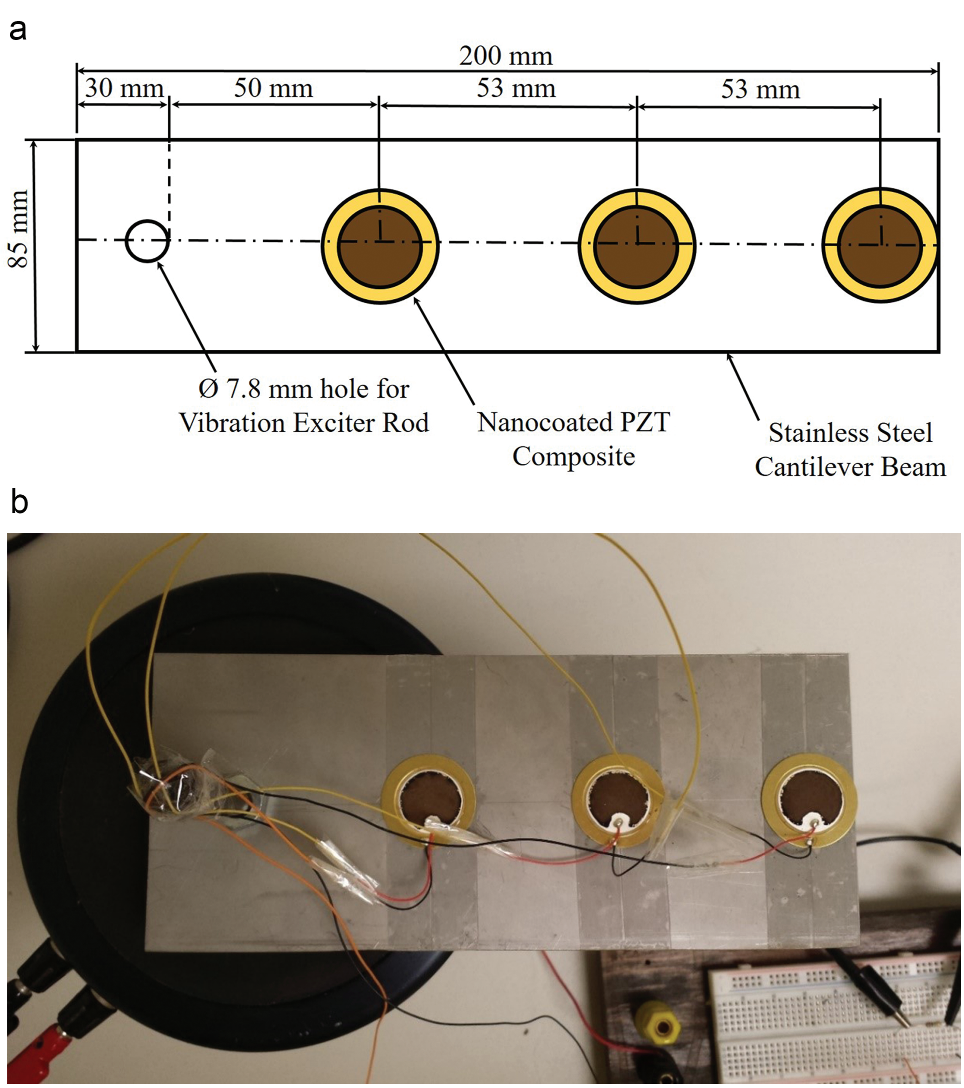

Figure 2: Rectangular stainless steel cantilever beam with three nano-coated PZT composites. (A) Design schematic. (B) Actual picture.

mounted in the vibration exciter. After the data has been recorded for nano-coated PZT composite system, same procedure is executed for the non-coated PZT composite system.

For the consistent comparison in the course of optimization process through three shapes, the following parameters are kept constant for nano-coated and non-coated structures.

- Number of nano-coated and non-coated PZT composites
- Thickness, longitudinal (axial) length, top view area of the steel cantilever beam
- Axial position of PZT composites from vibration exciter fixture rod
- Frequency of vibration

Design schematic and actual picture of the three energy harvesting structures are shown in Figure 2 (Rectangular), Figure 3 (Trapezoidal) and Figure 4 (Triangular).

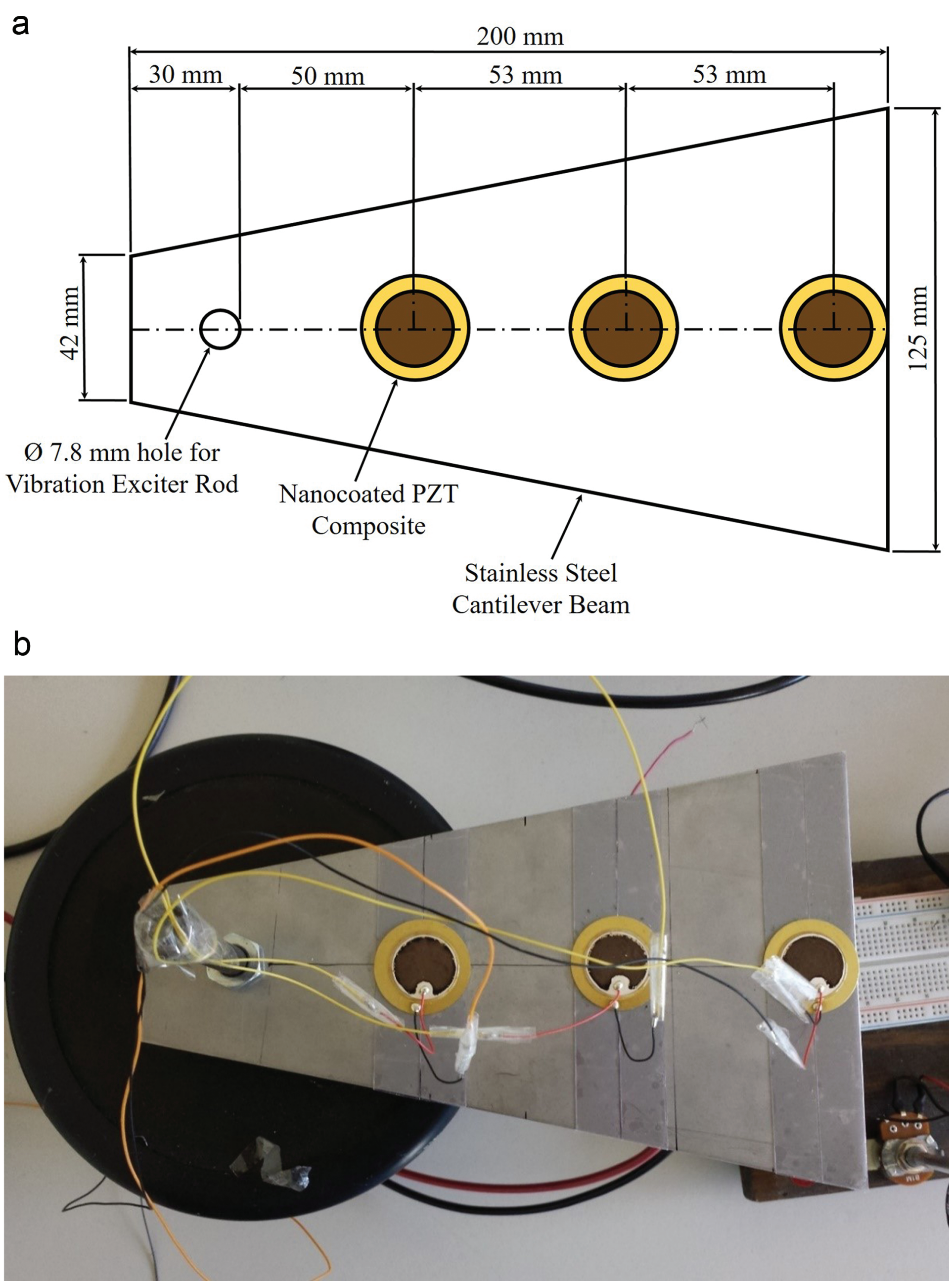

Figure 3: Trapezoidal stainless steel cantilever beam with three nano-coated PZT composites. (A) Design schematic. (B) Actual picture.

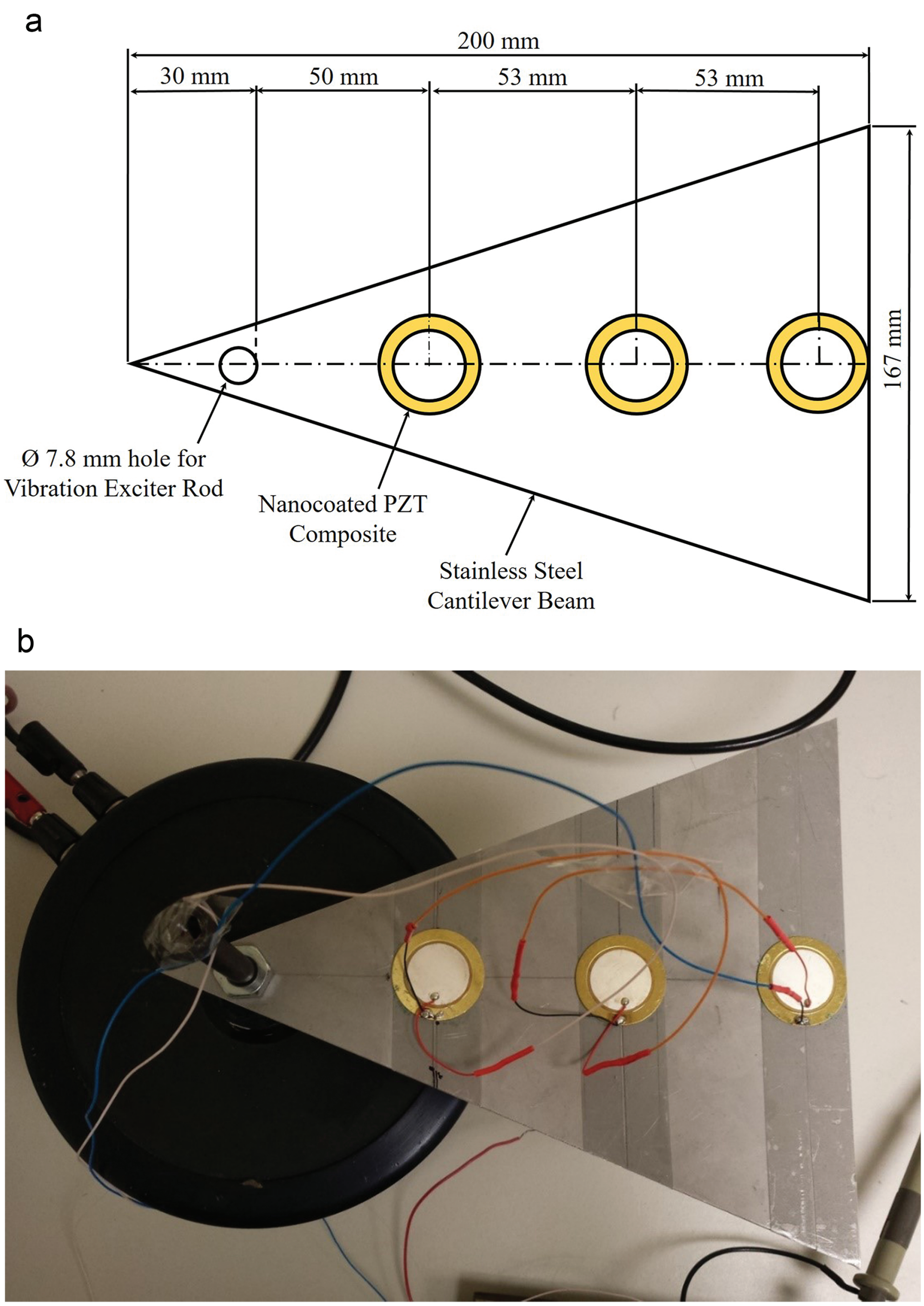

Figure 4: Triangular stainless steel cantilever beam with three non-coated PZT composites. (A) Design schematic. (B) Actual picture.

Experimental Setup

Steel cantilever beam with PZT composites is the energy harvesting component of the experimental procedure. The schematic and the actual picture of the experimental laboratory setup with the labeling of the parts of the overall system is illustrated in Figures 5 and 6 respectively. The PZT composite energy harvester is mounted on the Brüel & Kjær type 4809 vibration exciter. A sine wave signal (Specifications: Sine Curve, 0.00 Phase and 1.000 V_{pp} Amplitude) from Tektronix AFG 3021 signal generator is supplied as an input signal to the vibration exciter. Stewart world 600 power amplifier is connected between signal generator and vibration exciter to amplify the input signal so that it reaches the requirement of the vibration exciter for the experimental procedure. Vibrational energy

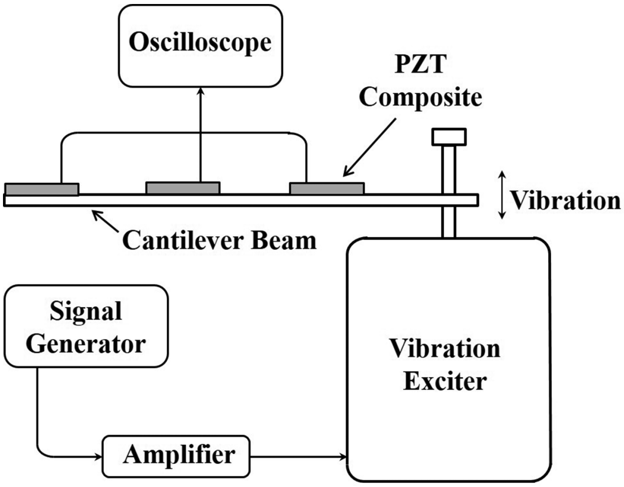

Figure 5: Schematic of experimental laboratory setup.

is provided to excite the PZT composite cantilever system by vibration exciter. The output AC voltage generated from the system is measured by Tektronix 3012 oscilloscope. PZT composite cantilever system is excited in a frequency range of 20 Hz to 1000 Hz. The waveform of output voltage in oscilloscope screen is stable and continuous and output RMS voltage reading is consistent after exciting the system for 60 seconds. Thus, the RMS voltage data is taken after vibrating the system for exactly 60 seconds.

For measuring the output voltage data from the system, a resistor with a known resistance value is utilized in the experimental set up for output power comparison purposes. The resistor is connected to the PZT composite and voltage reading is taken across the resistor. Three PZT composites are configured in series connection for the high voltage and power output. When the external and internal impedance match, the power output is maximum (Kim, H. et al. 2007). The optimal resistive load of the system for maximum power output is found to be 1 MΩ. Power calculation is done from this optimal resistive load and RMS voltage using the equation $P = V_{rms}^2/R$ and where P, V and R stands for power in watts, voltage in volts and resistance in ohms respectively. The experimental procedure is carried out for nano-coated system first. After that the nano-coated PZTs are removed from the cantilever beam and the same cantilever beam is used for the non-coated PZTs for the experimental procedure.

Results and Discussion

Impact of Nano-Mixture Coating on PZT Composite Rectangular Energy Harvester

This work considers the impact of the special nanoparticle mixture coating on the piezoelectric energy harvesting capability of conventional PZT composite. Rectangular cantilever beam structure is considered for the energy harvesting system. Experimental procedure is conducted for non-coated PZT composite energy harvester in the predefined frequency range for its power harvesting capability. The nanoparticle mixture coating is applied on the PZT composite and then the piezoelectric power output is analyzed for nano-coated PZT composite energy harvester in the same frequency

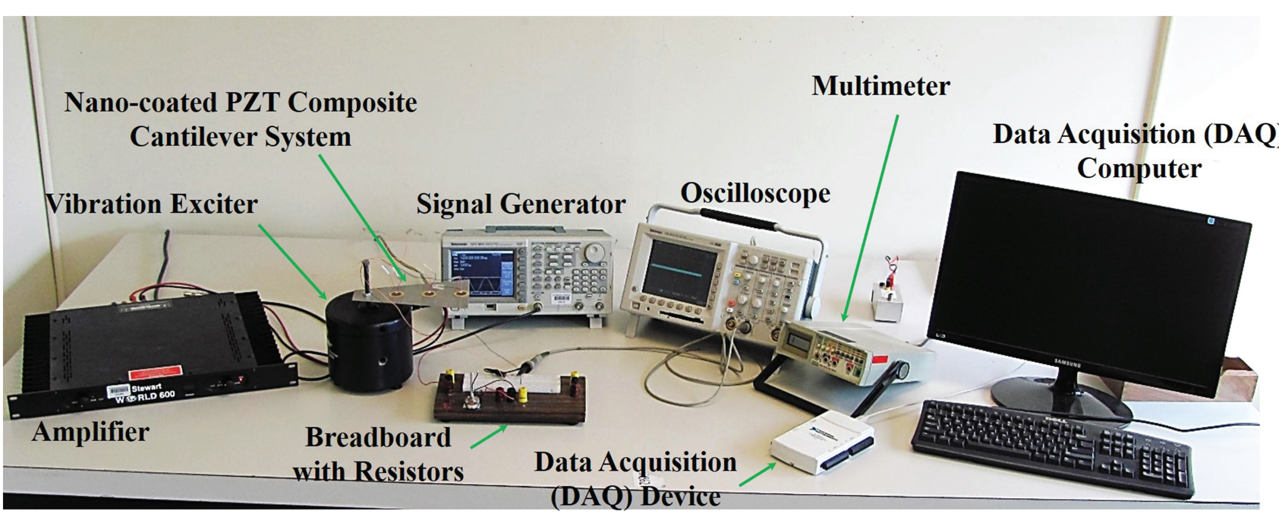

Figure 6: Experimental laboratory setup.

range. As the main focus of this work is to improve the power harvesting capability of conventional non-coated PZT composite, the nano-coated multi PZT cantilever system and the non-coated multi PZT cantilever system is experimented for its power harvesting capability using the methods outlined. Experimental result of the power generation from the input vibration is shown in the Table 1. For both nano-coated system and non-coated system, there are two peak power outputs at two different frequencies. For the nano-coated system, two peaks occur at 80 Hz and 350 Hz whereas for non-coated system, two peaks occur at 80 Hz and 400 Hz. Nano-coated system has peak power output of 615.536 microwatt at 350 Hz frequency whereas non-coated system has peak power output of 326.886 microwatt at 400 Hz. Similarly, nano-coated system and non-coated system has peak power output of 503.105 microwatt and 395.612 microwatt respectively at 80 Hz frequency.

Figure 7 shows the power generation profile for the nano-coated and non-coated PZT systems. The power enhancement impact of nano-mixture coating is 88.3 % for the first scenario and 27.17 % for the second scenario mentioned above. The result show that the nano-mixture coating has better enhancement impact at higher input

Table 1: Power generation impact of nano-mixture coating on rectangular cantilever energy harvesting system.

Case	Frequency (Hz)	Non-coated multi PZT Cantilever System		Nano-coated multi PZT Cantilever System	
		Voltage (volt)	Power (microwatt)	Voltage (volt)	Power (microwatt)
1	20	2.125	4.516	5.316	28.260
2	40	2.893	8.369	4.439	19.705
3	60	6.624	43.877	6.811	46.390
4	80	19.890	395.612	22.430	503.105
5	100	6.058	36.699	6.615	43.758
6	150	2.281	5.203	2.253	5.076
7	200	2.725	7.426	1.510	2.280
8	250	0.640	0.410	2.887	8.335
9	300	2.683	7.198	3.488	12.166
10	350	5.179	26.822	24.810	615.536
11	400	18.080	326.886	9.615	92.448
12	600	0.664	0.441	0.842	0.709
13	800	0.858	0.736	1.533	2.350
14	1000	0.662	0.438	0.361	0.130

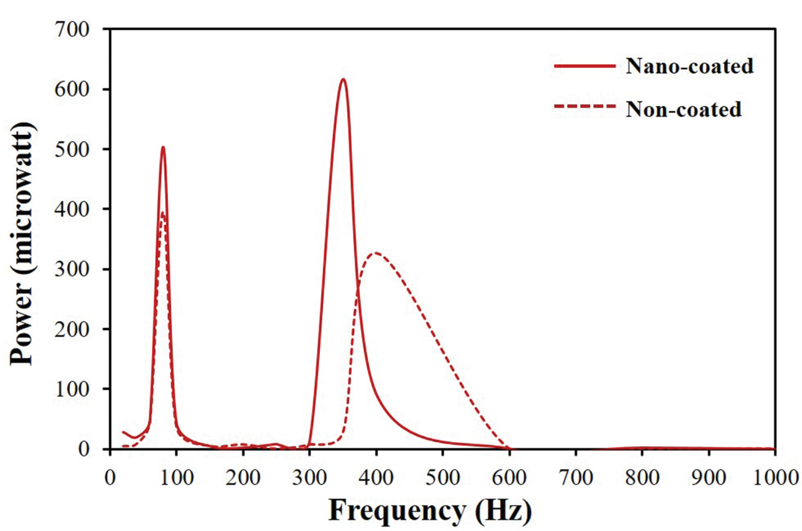

Figure 7: Power generation profiles for non-coated multi PZT rectangular cantilever system and nano-coated multiple PZT rectangular cantilever system at different frequencies.

frequency of 400 Hz as compared to the enhancement at 80 Hz. For the non-coated system, PZT is the piezoelectric materials and electromechanical component which generate power from the input vibration. Whereas in nano-coated system, ZnO nanoparticles in the nano-mixture coating and PZT in the substrate are the piezoelectric materials and electromechanical components. The power harvesting potential in nano-coated system is increased due to the piezoelectric function of ZnO. Thus the increment in power harvesting efficiency is due to the addition of nano-mixture coating in the system and for the same input vibrational energy, nano-coated system is able to harvest higher energy than non-coated system.

Alternative Structures and Their Comparison with Rectangular System

For trapezoidal shaped energy harvesting system, two peak power output occurs at the frequency of 80 Hz and 250 Hz for both nano-coated and non-coated systems. Power outcome for nano-coated system is 188.513 W at the frequency of 80 Hz and its 54.76 microwatt for non-coated system. 205.923 microwatt and 195.44 microwatt are generated for nano-coated system and non-coated system at the frequency of 250 Hz. The power generation results for the trapezoidal energy harvesting system are presented in Table 2. The adjacent Figure 8 depicts the

Table 2: Power generation impact of nano-mixture coating on trapezoidal cantilever energy harvesting system.

Case	Frequency (Hz)	Non-coated multi PZT Cantilever System		Nano-coated multi PZT Cantilever System	
		Voltage (volt)	Power (microwatt)	Voltage (volt)	Power (microwatt)
1	20	0.981	0.962	1.824	3.327
2	40	1.108	1.228	2.351	5.527
3	60	2.217	4.915	4.705	22.137
4	80	7.400	54.760	13.730	188.513
5	100	2.300	5.290	3.466	12.013
6	150	1.744	3.042	1.579	2.493
7	200	1.004	1.008	1.958	3.834
8	250	13.980	195.440	14.350	205.923
9	300	0.740	0.548	1.612	2.599
10	350	1.749	3.059	1.555	2.418
11	400	1.885	3.553	1.535	2.356
12	600	1.748	3.056	1.661	2.759
13	800	1.950	3.803	1.575	2.481
14	1000	1.752	3.070	1.574	2.477

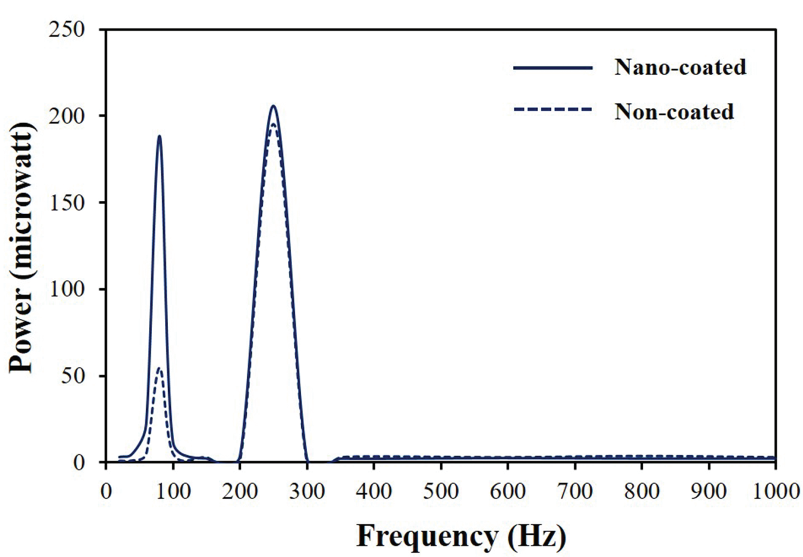

Figure 8: Power generation profiles for non-coated multi PZT trapezoidal cantilever system and nano-coated multiple PZT trapezoidal cantilever system at different frequencies.

power harvesting profile from the result. At 80 Hz frequency, power harvesting efficiency of the piezoelectric energy harvesting system is increased by 244.25 % because of the application of nano-mixture coating. And the power harvesting enhancement is 5.36 % at the frequency of 250 Hz.

Experimental result of power generation for triangular piezoelectric energy harvesting system is shown in Table 3. Two peak values of power generation from the input vibration occur at the frequency of 60 Hz and 80 Hz respectively. Nano-coated system has power outcome of 68.89 microwatt whereas non-coated system has power outcome of 9.181 microwatt at the frequency of 60 Hz. Similarly, nano-coated system and non-coated system has power outcome of 57.093 microwatt and 5.808 microwatt respectively at 80 Hz frequency. Figure 9 depicts the power generation profile for the nano-coated and non-coated systems. It can be observed that 883 % of power generation enhancement is obtained in nano-coated system at 80 Hz frequency and 650.35 % at 60 Hz frequency.

Power generation enhancement results of nano-coated PZT system over non-coated PZT system for the three energy harvesting systems are summarized in Table 4. Based on the results, rectangular cantilever energy harvesting system demonstrated better power harvesting capability than trapezoidal and triangular systems for both nano-coated and non-coated systems. Out of the three structures, the rectangular structure

Table 3: Power generation impact of nano-mixture coating on triangular cantilever energy harvesting system.

Case	Frequency (Hz)	Non-coated multi PZT Cantilever System		Nano-coated multi PZT Cantilever System	
		Voltage (volt)	Power (microwatt)	Voltage (volt)	Power (microwatt)
1	20	0.732	0.536	0.844	0.712
2	40	1.051	1.105	1.983	3.932
3	60	3.03	9.181	8.3	68.89
4	80	2.41	5.808	7.556	57.093
5	100	0.887	0.787	2.544	6.472
6	150	0.585	0.342	0.806	0.65
7	200	1.327	1.761	1.007	1.014
8	250	0.88	0.774	0.911	0.83
9	300	0.641	0.411	0.706	0.498
10	350	0.658	0.433	0.863	0.745
11	400	0.758	0.575	1.045	1.092
12	600	0.637	0.406	0.301	0.091
13	800	0.619	0.383	0.413	0.171
14	1000	0.584	0.341	0.212	0.045

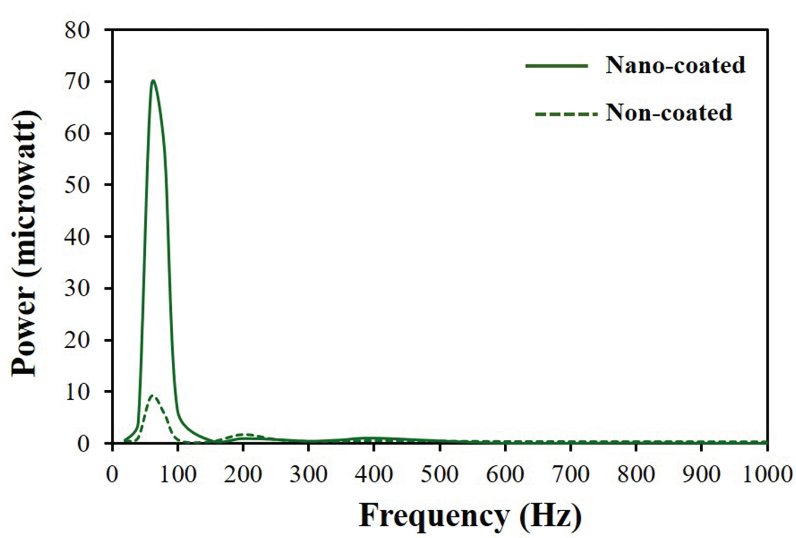

Figure 9: Power generation profiles for non-coated multi PZT triangular cantilever system and nano-coated multi PZT triangular cantilever system at different frequencies.

Table 4: Percentage enhancement and power generation comparison for the three systems.

Structural Geometry	Frequency (Hz)	Power Generation (microwatt)		Net Power Enhancement (microwatt)	Percentage Power Enhancement
		Non-coated System	Nano-coated System		
Rectangular	80	**395.612**	503.105	107.493	27.17
	350 and 400	326.886	**615.536**	**288.65**	**88.3**
Trapezoidal	80	54.76	188.513	**133.753**	**244.25**
	250	195.44	205.923	10.483	5.36
Triangular	60	9.181	68.89	**59.709**	650.35
	80	5.808	57.093	51.285	**883**

has the optimum power generation which is 615.536 microwatt for nano-coated system and 395.612 microwatt for non-coated. The occurrence of the maximum power output in the rectangular cantilever structure is contrast to the results in the literature (Baker, Roundy, and Wright 2005; Benasciutti et al. 2010). This is because the literature considers the change in geometry of entire PZT in cantilever beam, whereas this work considers the change in geometry of the steel cantilever beam only, while the PZT shape remains circular in all the cases. The optimum impact in power generation due to the application of nano-mixture coating in the three structures is illustrated in Figure 10. Among the three structures, power enhancement percentage due to the application of nano-coating mixture is highest for the triangular structure which is 883. Optimum power enhancement percentage is 244.25 for trapezoidal structure and 88.3 for rectangular structure. Whereas net power enhancement of 288.65 microwatt can be observed for the rectangular structure which is highest among the three structures. The net power enhancement is 133.753 microwatt and 59.709 microwatt for trapezoidal and triangular structures respectively. Based on the results, interesting trend of net power enhancement and percentage enhancement between the three structure can be observed. In terms of percentage enhancement, triangular structure > trapezoidal structure > rectangular structure whereas in terms of net power enhancement, rectangular structure > trapezoidal structure > triangular structure. Additionally, one of the peak power generation occurs at the frequency of 80 Hz for all three cases.

The input vibrational energy transfers from cantilever beam structure to the main energy harvesting component of the system, nano-coated and non-coated PZT composites. Better the energy transfer capability of the structure to the PZT composites, higher is the power generation. Rectangular cantilever beam structure generated higher

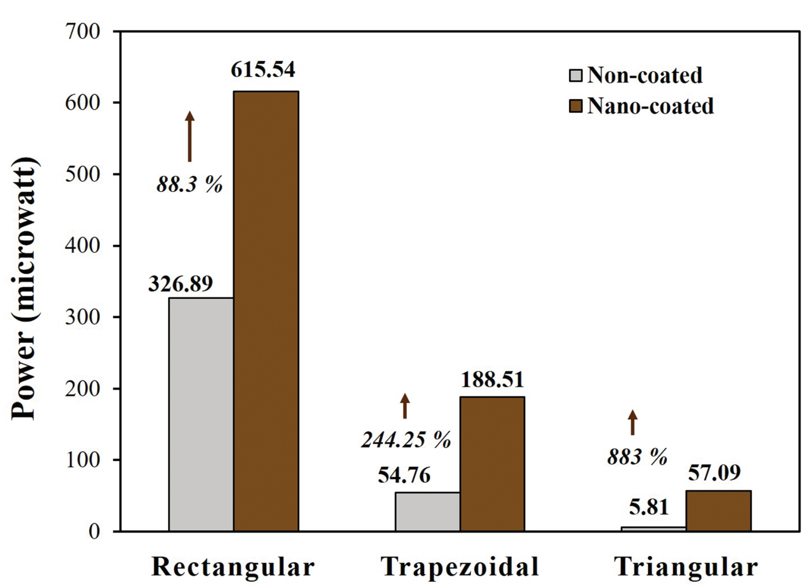

Figure 10: Optimum impact comparison of three energy harvesting structures.

power than trapezoidal and triangular structures due to its better structural efficiency in transferring vibrational energy from the input source to the nano-coated and non-coated PZT composites. This explanation applies for trapezoidal structure performing better than triangular structure in terms of power harvesting capability. Impact of the nano-mixture coating can be analyzed through net power enhancement and percentage power enhancement of the energy harvesting system. For the higher net power enhancement cases, 288.65 microwatt for rectangular, 133.753 microwatt for trapezoidal and 59.09 microwatt for triangular, the non-coated system has power generation of 326.886 microwatt, 54.76 microwatt and 9.181 microwatt respectively for the three structures. The reflects the proportionality of power generation and net power enhancement impact in these specific cases. Percentage power enhancement due to the application of nano-mixture coating is the overall increment of power harvesting efficiency of the energy harvesting system. The increment in triangular structure has the highest value of 883 %, followed by 244.25 % for rectangular structure and 88.3 % for triangular structure. Thus, the enhancement impact of nano-mixture coating on power harvesting efficiency is higher in triangular PZT energy harvesting system than trapezoidal and rectangular systems.

Conclusions

Nano-coated PZT energy harvesting system showed substantial and explicit improvement as compared to non-coated PZT energy harvesting system. In the rectangular cantilever system, the maximum power output in nano-coated PZT system is 615.536 microwatt and the corresponding power output for non-coated PZT system is 326.886 microwatt. Thus, the enhancement due to the nano-mixture coating is 88.30 %. In the trapezoidal cantilever system, the power output is enhanced from 54.760 microwatt to 188.513 microwatt at 80 Hz frequency, which is an improvement of 244.25 %. Similarly, in the triangular case the power output is enhanced from 5.808 microwatt to 57.093 microwatt at 80 Hz frequency, which is an improvement of 883 %. In the experimental analysis of this project work, the rectangular cantilever system performed substantially better than the trapezoidal and triangular cantilever systems in terms of power harvesting capability. However, the enhancement of power harvesting due to the nano-mixture coating is highest in triangular cantilever system.

Piezoelectric materials can be used to recover vibrational energy from intermodal transport system. These materials have great potential for harvesting vibrational energy. However, the power generated by the piezoelectric material is noticeably low which has caused limitations in the application of these materials in the energy harvesting. This work explores the nano-mixture coating capability to enhance power harvesting capability of conventional PZT material. The nano-mixture coating is the composition of 40 % ZnO, 58 % ferrofluid and 2 % epoxy binder by weight. This article presents an experimental study on the impact of nano-mixture coating on the conventional PZT energy harvester. Based on the experimental results, nano-coated PZT system show significant and explicit improvement as compared to non-coated PZT system. This work clearly demonstrate that the nano-mixture coating can be integrated into the conventional piezoelectric energy harvesting to enhance its power harvesting capability.

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