CHAPTER 6

CONCLUSIONS AND FUTURE SCOPES

The final chapter summarizes the findings of this study and highlights the novel and original contributions. The suggestions for future research to extend this study and a list of publications resulting from this research are presented. For more information, the reader is recommended to the comprehensive conclusions in each chapter.

6.1 Overview

The starting point of this research is an extensive literature review, giving a brief general overview of the field of energy harvesting and the challenges associated with increasing the PD and VPM of the commonly used PVEHs for transverse and rotational motion applications

This research has yielded two different harvester shapes for improving the performance of the PVEHs, which are parabolic and exponentially tapering width.

Firstly, this work reports a nonlinear analytical solution for the parabolic converging width unimorph PVEH with tip load mass under the influence of transverse base excitation. The nonlinearities associated with the geometry and piezoelectric material are considered in the mathematical model. The mass normalized mode shapes are obtained using Galerkin's discretization technique. The solutions of the system are acquired with the help of the method of multiple scales. The accuracy of the formulations is verified using experimental methods and also comparing with other reported nonlinear models. Finally, the effects of the taper parameter and the piezoelectric patch thickness on the voltage response and nonlinearity of the PVEH are studied.

After that, an analytical formulation of the parabolic and exponentially tapering width PVEH is presented. The formulations are verified using FE simulation in ANSYS and experimental methods. Finally, the parameters that affect the self-tuning characteristics of the RVEH are identified and discussed for their effects on the harvester's self-tunability.

6.2 Conclusions

The research presented in this thesis aims to give readers a better understanding of the electromechanically coupled modeling of PVEH systems in transverse and rotational motion applications. The findings of this research are likely to improve RVEH system modeling and contribute to their application in self-frequency tuning. The following is a summary of the study's main findings.

1. The results show that decreasing the harvesting beam's width and the piezoelectric patch's thickness decreases the PVEH's output voltage. The tapered PVEH generates higher VPM than its uniform width counterpart. A similar trend is observed for harvester with a thinner piezoelectric patch. At 10g acceleration, the VPM of the harvester with ϕ=0.6 is found to be 16.30% higher

than the uniform width counterpart and the PVEH with t_p =0.15 mm is 10.24% higher than the model with t_p =0.30 mm.

2. The linear formulations are not adequate for excitation amplitudes above 2.5g. At 10g acceleration, the maximum eccentricity of 64.47% and 63.51% is observed for the VEH model with ϕ= 0.2, t_p =0.30 mm and ϕ= 0, t_p =0.20 mm, respectively. Reducing the piezoelectric patch thickness limits the maximum deflection that the harvesting beam can withstand and diminishes the scope of harvesting the maximum available abundant vibration energy.
3. For the parabolic tapering RVEH, an upsurge in the taper parameter decreases the generated voltage significantly. However, the VPM of the harvester is increased from 15.4778 V/Kg to 19.404 V/Kg with an increase of taper parameter from 0 to 0.8. An increase in the length of the piezoelectric-coupled beam increases the generated voltage. The VPM is increased from 16.6061 K/Kg to 19.525 V/Kg with the length change from 52 mm to 92 mm. The peak open-circuit voltage drops from 559.9 mV to 420.6 mV when the radius of rotation increases from 77 mm to 87 mm.
4. The rotational harvester's proposed parabolic tapering width increases the VPM and PAF. For a system with t_p =0.254 mm, l =72 mm, ϕ =0.4, b_0 =50 mm, t_h =0.5 mm, r =7.5 mm, and M_L =15.1808 gram, the VPM and PAF are obtained as 30.88 V/Kg and 4.18, respectively. Compared to other reported models, these are noticeable improvements.
5. The exponentially tapering RVEH shows the peak OC voltage, VPM, and PD are 2.575 V, 28.15 V/Kg, and 5.27 μW/mm^3 at the rotational driving frequency of 6.65 Hz.

6. The tip load mass, active length, width, and thicknesses of the host and PZT patch, are operational in manipulating the zero-driving-frequency. The overall radius of rotation is responsible for broadband operation, where the centrifugal force dominates. The frequency of the peak output voltage moves to higher frequencies when the hub radius is increased. In addition, the harvester's overall size set constraints on the maximum value of the hub radius and the length of the harvesting beam.

6.3 Proposals for Future Research

The findings of this study have had a considerable impact on the modeling of PVEH systems and their application to self-frequency tuning. The following ideas for extending on the research in this thesis are made:

1. The proposed tapering width RVEH models presented in this article can be implemented for other efficiency-enhancing techniques (bimorph systems) for even better performance.

2. Various frequency self-tuning techniques can be combined with the proposed model to improve the performance in a wide frequency range.

3. Various electronic circuits can be designed and implemented to process the signals and store the harvested power, especially for low frequency applications.

4. Research can be done on the packaging of the harvester and implement it on operating machines.

5. Develop an optimization model to identify the best configuration parameters to achieve the highest VPM.

6. Estimation of the performance of the RVEH under random and band-limited excitations.

6.4 Publications

Journals

- **Chand, R.R.**, Tyagi, A. Parametric Analysis of a Rotational Piezoelectric-Coupled Tapered-Bimorph Structure with Various Boundary Conditions Under Transient Axial Loading. *Journal of Vibration Engineering & Technology,* **9**, 907–917 (2021). https://doi.org/10.1007/s42417-020-00272-9
- **Chand, R.R.**, Tyagi, A. Investigation of the Effects of the Piezoelectric Patch Thickness and Tapering on the Nonlinearity of a Parabolic Converging Width Vibration Energy Harvester. *Journal of Vibration Engineering & Technology,* **10**, 1–18 (2021). https://doi.org/10.1007/s42417-021-00359-x
- **Chand, R.R.**, Tyagi, A. Design and experimental validation of an exponentially tapering width rotational piezoelectric vibration energy harvester. *Journal of Intelligent Material Systems and Structures* (2022) (Accepted for publication).
- **Rakesh Ranjan Chand** and Amit Tyagi, Design and Parametric Analysis of a novel Parabolic Tapering Cross-section Rotational Vibration Energy Harvester (Under Review).