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).

Conferences

- Chand R.R., Tyagi A. (2021) Parametric Investigation of a Rotational Parabolic-Tapered Cantilever with Elliptical Sectional Area Exposed to Variable Thermal Gradient and Axial Dynamic Load. *Recent Advances in Mechanical Engineering. Lecture Notes in Mechanical Engineering, Springer*, Singapore. https://doi.org/10.1007/978-981-15-8704-7_8
- **Rakesh Ranjan Chand** and Amit Tyagi, Parametric Study of a Revolving Piezoelectric Tapered-Bimorph beam Subjected to Pulsating Axial load Considering Various Boundary Conditions. *Progressive research in Industrial and Mechanical Engineering* (Awaiting publication).
- **Rakesh Ranjan Chand** and Amit Tyagi, A highly efficient tapering width bimorph rotational vibration energy harvester subjected to dynamic axial excitation. *Progressive research in Industrial and Mechanical Engineering* (Awaiting publication).

Appendix I

The coefficients of the Equation (3.17) are;

$$M_{ij}=\left(\rho_h A_h+\rho_p A_p\right)\int_0^{l_e}\psi_i\psi_j\left(1-4\sqrt{\phi x}\right)dx+M_{LM}\psi_i\left(l_e\right)\psi_j\left(l_e\right)+I_{LM}\psi_i'\left(l_e\right)\psi_j'\left(l_e\right),$$

$$f_{ijkl}=\left(\rho_h A_h+\rho_p A_p\right)\int_0^{l_e}\left(\int_0^x\psi_i'\psi_j'dh\right)\left(\int_0^x\psi_k'\psi_l'dh\right)\left(1-4\sqrt{\phi x}\right)dx$$

$$+M_{LM}\left(\int_0^{l_e}\psi_i'\psi_j'dx\right)\left(\int_0^{l_e}\psi_k'\psi_l'dx\right),$$

$$Y_{ijkl}=\left(E_h I_h+E_p I_p\right)\left(\int_0^{l_e}\psi_i''\psi_j''\psi_k'\psi_l'\left(1-4\sqrt{\phi x}\right)dx+\int_0^{l_e}\psi_k''\psi_l''\psi_i'\psi_j'\left(1-4\sqrt{\phi x}\right)dx\right),$$

$$H_{ij}=\left(E_h I_h+E_p I_p\right)\int_0^{l_e}\psi_i''\psi_j''\left(1-4\sqrt{\phi x}\right)dx, B_{ijk}=\frac{3}{2}\alpha_1\int_0^{l_e}\psi_i''\psi_j''\psi_k''\left(1-4\sqrt{\phi x}\right)dx,$$

$$\gamma_i=\frac{1}{2}\alpha_2\int_0^{l_e}\psi_i''\left(1-4\sqrt{\phi x}\right)dx, \lambda_i=\frac{1}{4}\alpha_3\int_0^{l_e}\psi_i''\left(1-4\sqrt{\phi x}\right)dx,$$

$$F_{ij}=\alpha_4\int_0^{l_e}\psi_i''\psi_j''\left(1-4\sqrt{\phi x}\right)dx, D_{ijk}=\frac{1}{4}\alpha_2\int_0^{l_e}\begin{matrix}\left(\psi_i''\psi_j''\psi_k''+\psi_i'\psi_j''\psi_k'+\psi_i'\psi_j'\psi_k''\right)\\ \left(1-4\sqrt{\phi x}\right)dx\end{matrix}, \text{ and}$$

$$\Delta_i=-\left(\rho_h A_h+\rho_p A_p\right)\frac{1}{2}\int_0^{l_e}\psi_i\left(1-4\sqrt{\phi x}\right)dx-M_{LM}\psi_i\left(l_e\right),$$

in which,

$$\alpha_1=\frac{c_1}{8}b_0\left(z_2^4-z_1^4\right),\ \alpha_2=e_{31}b_0\left(z_2+z_1\right),$$

$$\alpha_3=\frac{c_2}{2t_p}b_0\left(z_2+z_1\right),\text{ and }\alpha_4=\frac{c_3}{3t_p}b_0\left(z_2^3-z_1^3\right)$$

Coefficients of Equation (3.19) are;

$$\varphi_i = e_{31} b_0 t_{pc} \int_0^{l_e} \psi_i'' \left(1 - 4\sqrt{\phi x}\right) dx, L_{ijk} = e_{31} b_0 t_{pc} \int_0^{l_e} \left(\frac{1}{2}\psi_i' \psi_j' \psi_k'' + \psi_i' \psi_j'' \psi_k'\right)\left(1 - 4\sqrt{\phi x}\right) dx,$$

$$C = \frac{\varepsilon_{33}^s b_0}{t_p} \int_0^{l_e} \left(1 - 4\sqrt{\phi x}\right) dx, G_{ij} = c_3 b_0 t_{pc}^2 \int_0^{l_e} \psi_i'' \psi_j'' \left(1 - 4\sqrt{\phi x}\right) dx, c_{4v} = \frac{c_4 b_0}{t_p^2} \int_0^{l_e} \left(1 - 4\sqrt{\phi x}\right) dx,$$

$$k_i = \frac{c_2 b_0 t_{pc}}{t_p} \int_0^{l_e} \psi_i'' \left(1 - 4\sqrt{\phi x}\right) dx, \text{ and } \chi_i = \frac{c_2 b_0 t_{pc}}{t_p} \int_0^{l_e} \psi_i'' \left(1 - 4\sqrt{\phi x}\right) dx$$

The differential equations are obtained by equating the same powers of ξ to zero as;

$$\frac{\partial^2}{\partial T_0^2} s_{10}\left(T_0, T_1, T_2\right) + \omega_1^2 s_{10}\left(T_0, T_1, T_2\right) = 0 \tag{I.1}$$

$$C\left(\frac{\partial}{\partial T_0} v_0\left(T_0, T_1, T_2\right)\right) + \frac{v_0\left(T_0, T_1, T_2\right)}{R_L} = -\varphi_1\left(\frac{\partial}{\partial T_0} s_{10}\left(T_0, T_1, T_2\right)\right) \tag{I.2}$$

$$\begin{aligned} &\frac{\partial^2}{\partial T_0^2} s_{10}\left(T_0, T_1, T_2\right) + \omega_1^2 s_{11}\left(T_0, T_1, T_2\right) = \lambda_1\left(v_0\left(T_0, T_1, T_2\right)\right)^2 \\ &-F_{11} s_{10}\left(T_0, T_1, T_2\right) v_0\left(T_0, T_1, T_2\right) + B_{111}\left(s_{10}\left(T_0, T_1, T_2\right)\right)^2 - 2\frac{\partial^2}{\partial T_0 \partial T_1} s_{10}\left(T_0, T_1, T_2\right) \end{aligned} \tag{I.3}$$

$$\begin{aligned} &C\left(\frac{\partial}{\partial T_0} v_1\left(T_0, T_1, T_2\right)\right) + \frac{v_1\left(T_0, T_1, T_2\right)}{R_L} = -C\left(\frac{\partial}{\partial T_1} v_0\left(T_0, T_1, T_2\right)\right) \\ &-\varphi_1\left(\frac{\partial}{\partial T_0} s_{11}\left(T_0, T_1, T_2\right) + \frac{\partial}{\partial T_1} s_{10}\left(T_0, T_1, T_2\right)\right) - L_{111}\left(s_{10}\left(T_0, T_1, T_2\right)\right)^2 \frac{\partial}{\partial T_0} s_{10}\left(T_0, T_1, T_2\right) \\ &+G_{11} s_{10}\left(T_0, T_1, T_2\right)\frac{\partial}{\partial T_0} s_{10}\left(T_0, T_1, T_2\right) + c_{4v} v_0\left(T_0, T_1, T_2\right)\frac{\partial}{\partial T_0} v_0\left(T_0, T_1, T_2\right) \\ &-k_1 s_{10}\left(T_0, T_1, T_2\right)\frac{\partial}{\partial T_0} v_0\left(T_0, T_1, T_2\right) - \sigma_1 v_0\left(T_0, T_1, T_2\right)\frac{\partial}{\partial T_0} s_{10}\left(T_0, T_1, T_2\right) \end{aligned} \tag{I.4}$$

$$
\begin{aligned}
&\frac{\partial^2}{\partial T_0^2}s_{12}\left(T_0,T_1,T_2\right)+\omega_1^2 s_{12}\left(T_0,T_1,T_2\right)=-2\frac{\partial^2}{\partial T_0\partial T_1}s_{11}\left(T_0,T_1,T_2\right)-2\frac{\partial^2}{\partial T_0\partial T_2}s_{10}\left(T_0,T_1,T_2\right)\\
&-\frac{\partial^2}{\partial T_1^2}s_{10}\left(T_0,T_1,T_2\right)-2\zeta_1\omega_1\frac{\partial}{\partial T_0}s_{10}\left(T_0,T_1,T_2\right)+\gamma_1 v_0\left(T_0,T_1,T_2\right)+2B_{111}s_{10}\left(T_0,T_1,T_2\right)\\
&\times s_{11}\left(T_0,T_1,T_2\right)-Y_{1111}\left(s_{10}\left(T_0,T_1,T_2\right)\right)^3+2\lambda_1 v_0\left(T_0,T_1,T_2\right)v_1\left(T_0,T_1,T_2\right)\\
&-f_{1111}\left(\frac{\partial^2}{\partial T_0^2}s_{10}\left(T_0,T_1,T_2\right)\right)\left(s_{10}\left(T_0,T_1,T_2\right)\right)^2-f_{1111}\left(\frac{\partial}{\partial T_0}s_{10}\left(T_0,T_1,T_2\right)\right)^2 s_{10}\left(T_0,T_1,T_2\right)\\
&+D_{111}\left(s_{10}\left(T_0,T_1,T_2\right)\right)^2 v_0\left(T_0,T_1,T_2\right)-F_{11}s_{10}\left(T_0,T_1,T_2\right)v_1\left(T_0,T_1,T_2\right)\\
&-F_{11}s_{11}\left(T_0,T_1,T_2\right)v_0\left(T_0,T_1,T_2\right)-\frac{1}{2}f\Delta_1 e^{i\omega_1 T_0}e^{i\sigma T_2}-\frac{1}{2}f\frac{\Delta_1}{e^{i\omega_1 T_0}e^{i\sigma T_2}}
\end{aligned}
\tag{I.5}
$$

$$
\begin{aligned}
&C\frac{\partial}{\partial T_0}v_2\left(T_0,T_1,T_2\right)+\frac{v_2\left(T_0,T_1,T_2\right)}{R_L}=-C\left(\frac{\partial}{\partial T_1}v_1\left(T_0,T_1,T_2\right)+\frac{\partial}{\partial T_2}v_0\left(T_0,T_1,T_2\right)\right)\\
&-\varphi_1\left(\frac{\partial}{\partial T_0}s_{12}\left(T_0,T_1,T_2\right)+\frac{\partial}{\partial T_1}s_{11}\left(T_0,T_1,T_2\right)+\frac{\partial}{\partial T_2}s_{10}\left(T_0,T_1,T_2\right)\right)\\
&-L_{111}\left(s_{10}\left(T_0,T_1,T_2\right)\right)^2\left(\frac{\partial}{\partial T_0}s_{11}\left(T_0,T_1,T_2\right)+\frac{\partial}{\partial T_1}s_{10}\left(T_0,T_1,T_2\right)\right)\\
&-2L_{111}s_{10}\left(T_0,T_1,T_2\right)s_{11}\left(T_0,T_1,T_2\right)\left(\frac{\partial}{\partial T_0}s_{10}\left(T_0,T_1,T_2\right)\right)+G_{11}s_{10}\left(T_0,T_1,T_2\right)\\
&\times\left(\frac{\partial}{\partial T_0}s_{11}\left(T_0,T_1,T_2\right)+\frac{\partial}{\partial T_1}s_{10}\left(T_0,T_1,T_2\right)\right)+G_{11}s_{11}\left(T_0,T_1,T_2\right)\left(\frac{\partial}{\partial T_0}s_{10}\left(T_0,T_1,T_2\right)\right)\\
&+c_{4v}v_0\left(T_0,T_1,T_2\right)\left(\frac{\partial}{\partial T_0}v_1\left(T_0,T_1,T_2\right)+\frac{\partial}{\partial T_1}v_0\left(T_0,T_1,T_2\right)\right)+c_{4v}v_1\left(T_0,T_1,T_2\right)\\
&\times\left(\frac{\partial}{\partial T_0}v_0\left(T_0,T_1,T_2\right)\right)-k_1 s_{10}\left(T_0,T_1,T_2\right)\left(\frac{\partial}{\partial T_0}v_1\left(T_0,T_1,T_2\right)+\frac{\partial}{\partial T_1}v_0\left(T_0,T_1,T_2\right)\right)\\
&-k_1 s_{11}\left(T_0,T_1,T_2\right)\left(\frac{\partial}{\partial T_0}v_0\left(T_0,T_1,T_2\right)\right)-\sigma_1 v_0\left(T_0,T_1,T_2\right)\\
&\times\left(\frac{\partial}{\partial T_0}s_{11}\left(T_0,T_1,T_2\right)+\frac{\partial}{\partial T_1}s_{10}\left(T_0,T_1,T_2\right)\right)-\sigma_1 v_1\left(T_0,T_1,T_2\right)\left(\frac{\partial}{\partial T_0}s_{10}\left(T_0,T_1,T_2\right)\right)
\end{aligned}
\tag{I.6}
$$

Appendix II

The coefficients of Equation (3.32);

$$o_1 = -\frac{2\left(R_L^2\omega_1^2C^2\sigma - \frac{1}{2}\omega_1 R_L^2 C\varphi_1\gamma_1 + \sigma\right)\omega_1}{2R_L^2\omega_1^2C^2 + 2} \tag{II.1}$$

$$o_2 = 0 \tag{II.2}$$

$$\begin{aligned} o_3 = {} & \frac{1}{96}\frac{1}{\omega_1^2\left(R_L^2\omega_1^2C^2 + {}^1\!/_4\right)\left(R_L^2\omega_1^2C^2+1\right)^2}(-24R_L^6\omega_1^{10}C^6E_{1111} + 36R_L{}^4((Y_{1111}C^4 \\ & +(\varphi_1 D_{111} + \frac{1}{6}G_{11}F_{11})C^8 + \frac{5}{6}\varphi_1((\sigma_1 - \frac{3}{5}k_1)F_{11} + \frac{2}{5}G_{11}\lambda_1)C^2 + \frac{5}{3}(\frac{1}{10}c_{4v}F_{11} \\ & +\lambda_1(\sigma_1 - \frac{3}{5}k_1))\varphi_1^2C + \frac{1}{3}c_{4v}\varphi_1^3\lambda_1)R_L^2 - \frac{3}{2}C^2 f_{1111})\omega_1^8C^2 + 8R_L^2(C^2(C^2B_{111} \\ & +CF_{11}\varphi_1 + \varphi_1^2\lambda_1)(-5C^2B_{111} - 2CF_{11}\varphi_1 + \varphi_1^2\lambda_1)R_L{}^4 + (\frac{81}{8}Y_{1111}C^4 + (\frac{45}{8}D_{111}\varphi_1 \\ & +\frac{3}{2}G_{11}F_{11})C^3 + \frac{33}{8}((\sigma_1 - \frac{9}{11}k_1)F_{11} + \frac{6}{11}G_{11}\lambda_1)\varphi_1C^2 + 3(\sigma_1\lambda_1 - \frac{1}{2}c_{4v}F_{11})\varphi_1^2C \\ & -\frac{3}{4}c_{4v}\varphi_1^3\lambda_1)R_L^2 - \frac{9}{2}C^2 f_{1111})\omega_1^6 + ((-90B_{111}^2C^4 - 67C^3B_{111}F_{11}\varphi_1 + (-54B_{111}\lambda_1 \\ & +F_{11}^2)\varphi_1^2C^2 - 5CF_{11}\varphi_1^3\lambda_1 - 4\varphi_1^4\lambda_1^2)R_L{}^4 + (54Y_{1111}C^2 + (9\varphi_1D_{111} + 6G_{11}F_{11})C \\ & +3\varphi_1((\sigma_1 - 3k_1)F_{11} + 2G_{11}\lambda_1)R_L^2 - 6f_{1111})\omega_1^4 + (-60B_{111}^2C^2 - 11CB_{111}F_{11}\varphi_1 \\ & +(-10B_{111}\lambda_1 - F_{11}^2)\varphi_1^2)R_L^2 + 9Y_{1111})\omega_1^2 - 10B_{111}^2) \end{aligned} \tag{II.3}$$

$$k_1 = \frac{2R_L^2\omega_1^2C^2\zeta_1 + R_L\omega_1\gamma_1 + 2\omega_1^2\zeta_1}{2R_L^2\omega_1^2C^2 + 2} \tag{II.4}$$

$$k_2 = 0 \tag{II.5}$$

$$
\begin{aligned}
k_3 = {} & \frac{9}{16}\frac{1}{\omega_1^2\bigl(R_L^2\omega_1^2C^2+{}^1\!/_4\bigr)\bigl(R_L^2\omega_1^2C^2+1\bigr)^2}\Bigl(\; R_L\Bigl(\; CR_L^4\Bigl(\; \frac{1}{3}c_{4v}\varphi_1^3\lambda_1 \\
& +\varphi_1^2\Bigl(\; \frac{5}{18}c_{4v}F_{11}+\lambda_1\Bigl(\; \sigma_1-\frac{7}{9}k_1 \;\Bigr)\Bigr)C+\frac{1}{6}C^2\Bigl(\; \frac{4}{3}CD_{111}+\Bigl(\; \sigma_1+k_1 \;\Bigr)F_{11} \\
& -\frac{2}{3}G_{11}\lambda_1 \;\Bigr)\varphi_1+\frac{1}{18}C^3G_{11}F_{11} \;\Bigr)R^4\omega_1^6+\frac{2}{9}R_L^2\Bigl(\; \varphi_1C\Bigl(\; \varphi_1\lambda_1-\frac{3}{2}CF_{11} \;\Bigr) \\
& \times\bigl(C^2B_{111}+CF_{11}\varphi_1+\varphi_1^2\lambda_1\bigr)R_L^2+\left(-\frac{1}{4}c_{4v}F_{11}+\frac{3}{2}\lambda_1\left(\sigma_1-\frac{1}{3}k_1\right)\right)\varphi_1^2 \\
& +\frac{3}{4}C\left(\frac{5}{3}CD_{111}+\bigl(\sigma_1+k_1\bigr)F_{11}-\frac{2}{3}G_{11}\lambda_1\right)\varphi_1+\frac{1}{2}C^2G_{11}F_{11} \;\Bigr)\omega_1^4 \\
& +\left(-\frac{1}{18}\varphi_1F_{11}\bigl(7C^2B_{111}+\varphi_1^2\lambda_1\bigr)R_L^2+\frac{1}{18}G_{11}F_{11}+\frac{1}{18}\varphi_1D_{111}\right)\omega_1^2-\frac{1}{18}G_{11}B_{111}\varphi_1 \;\Bigr)
\end{aligned}
\tag{II.6}
$$

Appendix III

The experimental setup for parabolic tapering width PVEH under transverse excitation is shown in Figure III.1. A SPECTRAL DYNAMICS shaker with a LYNX vibration control system and analyser provides the base excitation to the harvester. The harvester's electrodes are connected to the GWINSTEK (Model-GDS1054B) digital storage oscilloscope (DSO) to analyse the OC signals.

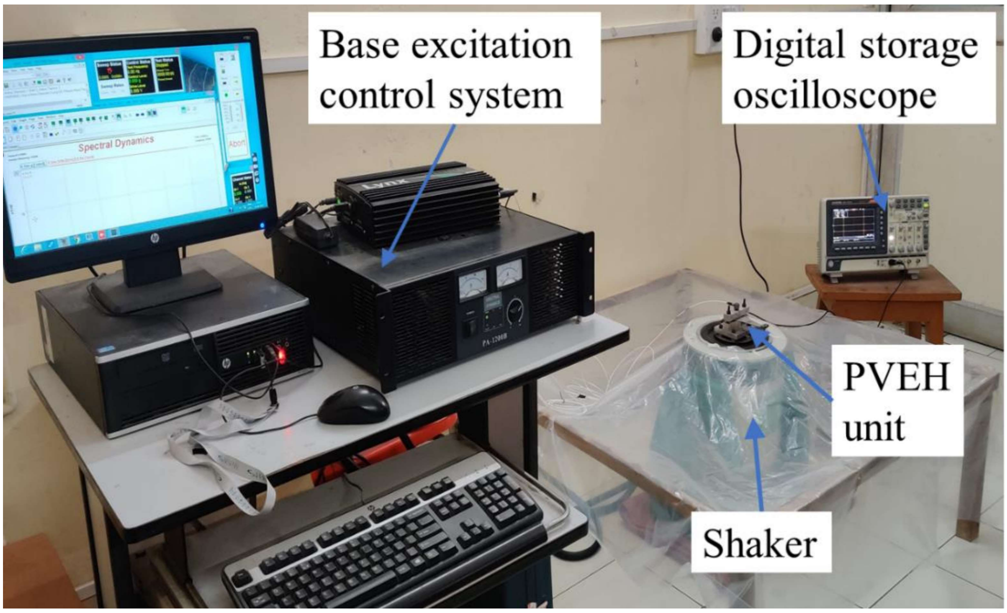

Figure III.1 Experimental setup used to test the PVEH and validate the mathematical model

Figure III.2 depicts the shaker configuration, which includes a mounting mechanism for the parabolic tapered PVEH. The excitation transmitted to the harvester is measured using the base accelerometer.

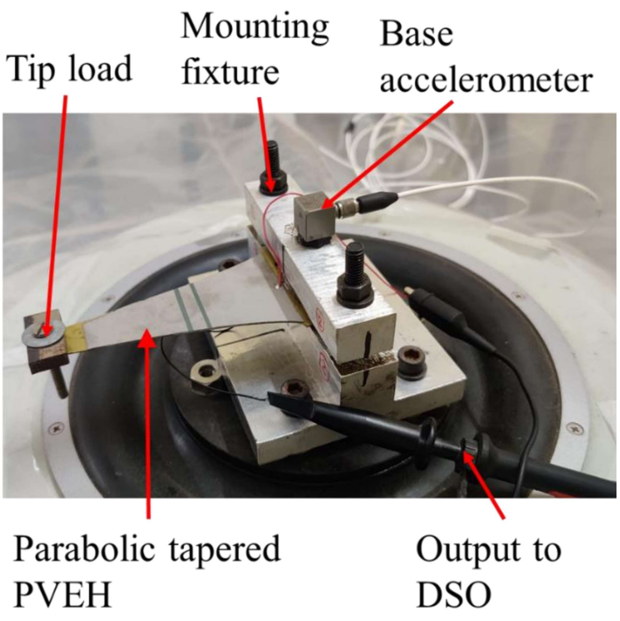

Figure III.2 Shaker arrangement with a fixture to mount the harvester

The various components of the harvester are shown in Figure III.3. As shown in Figure III.3a, the brass host beam is tapering parabolically from one end to the other. The parabolic host beam is cut in the Wire EDM machine by creating more than 100 key-points for each side using the coordinate expressions $p_1(0,0)$, $p_2(x, y(x))$, $p_3(x, [b_0 - y(x)])$, and $p_4(0, b_0)$ as demonstrated in Figure 3.1. The harvester with surface bonded PZT-5H patch along with the tip load mass is shown in Figure III.3b. Finally, the various tip load masses used in this experiment are shown in Figure III.3c.

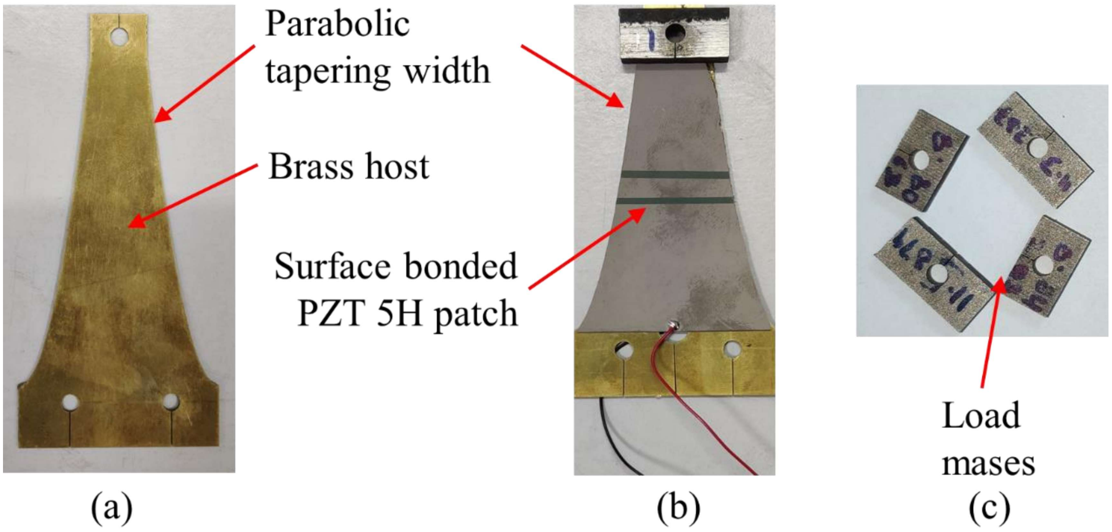

Figure III.3 The parabolic tapering width (a) brass host beam (b) harvester with surface bonded PZT 5H patch and (c) various load masses

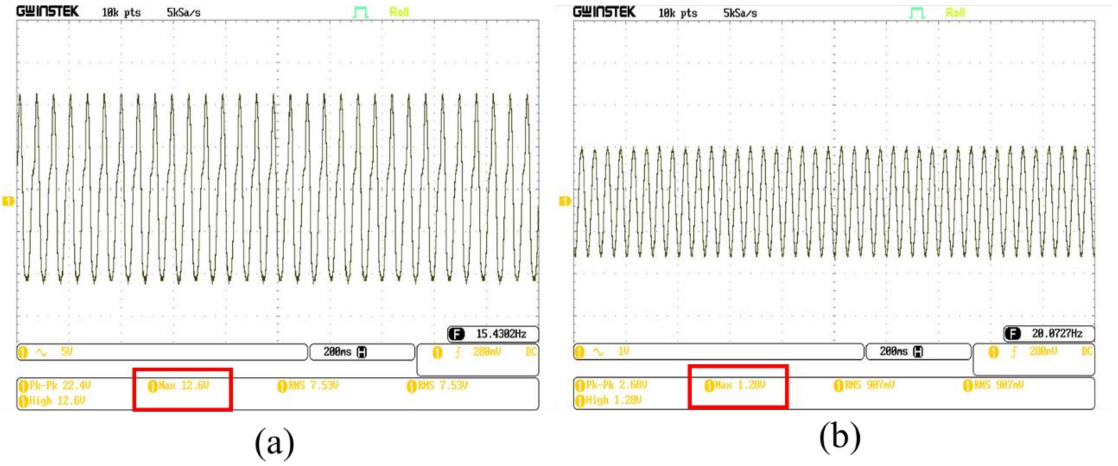

Figure III.4 For 10 g acceleration, the signal from the DSO under (a) 15.43 Hz and (b) 20.08 Hz excitation frequency

Figure III.4 shows the typical signals from the DSO under the 10 g acceleration level and two excitation frequencies. Figure III.4a shows a maximum OC voltage of 12.6 V for an excitation frequency of 15.43 Hz, which is nearer to the system's resonance frequency. Figure III.4b shows the OC response of the PVEH under 20.07 Hz excitation, for which maximum voltage is 1.28 V. This lower response is because the excitation frequency is far away from the resonance frequency.

Appendix IV

Experimental methods for the RVEHs:

The experimental setup for harvesting rotational energy and producing electrical voltage is shown in Figure IV.1. The parabolic and exponentially tapered PZT-coupled RVEHs used in this analysis are made up of a PZT-5H (from MIDE Technology Corporation, USA), surface-bonded on the parabolic tapered brass host. The parabolic and exponential profiles are cut using Wire EDM by creating more than 100 key points for each side (described in Appendix III) with a block of mild steel fixed at the free end. A regulated DC power supply (METRAVI RPS-3010) is used to regulate the speed of the motor (Revolution Technology, HSN/SAC 39219010), which drives the shaft. Figure IV.2 depicts the rotating shaft arrangement. Through a coupling, the shaft is connected to the motor. A tachometer is used to measure the rotating speed of the shaft. The tapered harvester is attached to the shaft using a cross hub. Through a slip ring (Lepakshi Enterprises, Model-B0713ZRG3), the generated voltage from the harvester is transmitted. Finally, the AC output signal is analyzed using a digital storage oscilloscope (GWINSTEK, Model-GDS1054B). The peak open-circuit output voltage from the harvester is measured for driving frequencies ranging from 0.7 – 20.1 Hz.

The parabolic tapered harvester with surface bonded PZT-5H patch along with the tip load mass is shown in Figure III.3b (Appendix III). The brass host beam and the surface bonded exponentially tapered RVEH are shown in Figure IV.3.

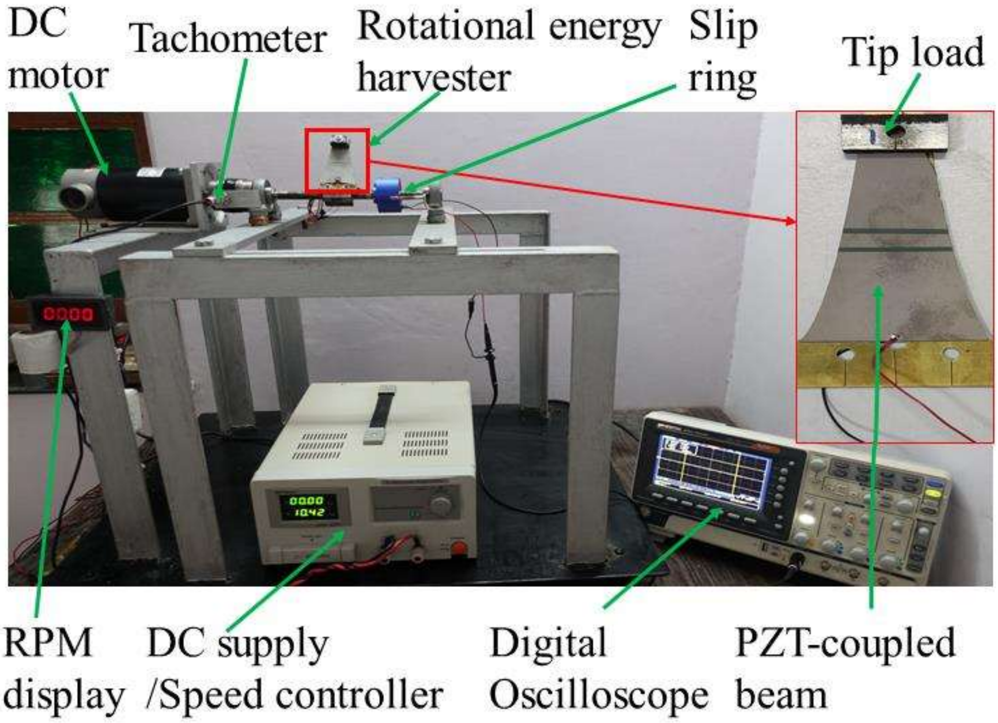

Figure IV.1 Experimental setup used to test the RVEH and validate the mathematical model

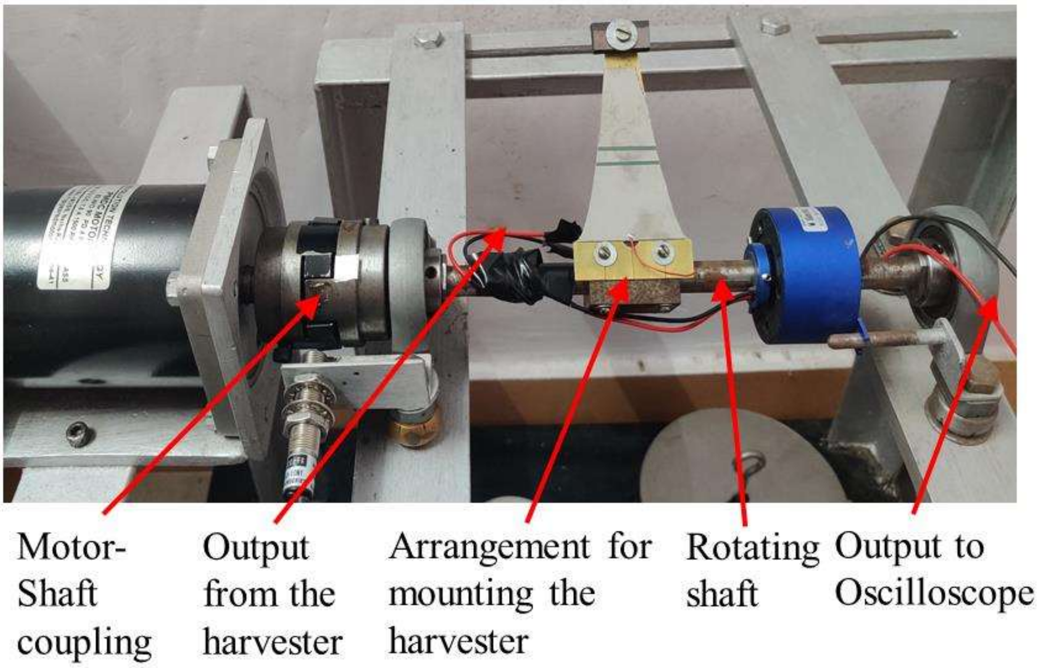

Figure IV.2 Rotating shaft arrangement with a cross hub to mount the harvester

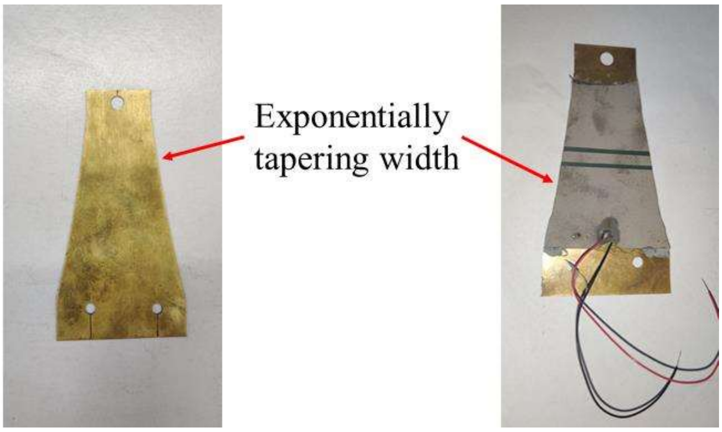

Figure IV.3 Exponentially tapering width PZT-coupled beam of the RVEH

Appendix V

List of Workshops/STC/Seminars Attended

- CSIR Sponsored Two Day National Seminar on “Emerging advancements in Smart Material Applications” (21.02.2019-22.02.2019) at Department of EEE, KEC, Perundurai, TN, India.
- Short Term Course (With Hands-on Training) on “Data Analytics and Predictive Technology Driven IoT based Smart Grid Infrastructure” March 1-6, 2021, by I-DAPT Hub Foundation, IIT(BHU), Varanasi
- MEMS Technology- Webinar Series”, 17th May to 9th June 2021, organized by Centre for Sensors, Vision Technology and Controls, Central Manufacturing Technology Institute, Bengaluru, India
- AICTE Training and Learning (ATAL) Academy Online Elementary FDP on “AICTE Training and Learning (ATAL) Academy Sponsored Program on “3D PRINTING DESIGN AND TECHNOLOGY”” from 2021-07-19 to 2021-07-23 at National Institute of Technology, Silchar, India.

List of International Conferences Attended

- International conference on “Innovative Technologies in Mechanical Engineering (ITME -2019)”, KIET Group of Institutions, Ghaziabad, Uttar Pradesh, India, October 18 -19, 2019.

- International Conference on “Progressive Research in Industrial & Mechanical Engineering (PRIME - 2021)” 5th -7th August 2021, National Institute of Technology, Patna, India (presented two papers).

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