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Nonlinear Piezoelectric Vibrational Energy Harvester using an Ortho-planar Spring and a H-I Structure for Powering IoT Sensors

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ABSTRACT: Wireless Sensor Networks (WSNs) for Internet of Things (IoT) applications rely on battery power, however, batteries need regular replacement and contain hazardous chemicals. The average power demand for powering IoT sensor is 1 µW-1 mW. This research proposes a novel piezoelectric vibrational energy harvester (PVEH) design using an ortho-planar spring and a H-I structure. PZT-5H is considered as piezoelectric material. The structure was fabricated using polylactide (PLA). Finite element analysis (FEA) and experimentation were performed to investigate the dynamical and electrical behavior of the proposed design in the vertical (z) axis. Experimentally, the results show that the PVEH exhibits softening nonlinearity and chaotic behaviour (pre-load due to gravitation), reaching a maximum output power of 1.01 mW and a bandwidth of 6.8 Hz under 0.6 g sine sweep excitation between 6 Hz and 15 Hz, where most ambient vibration sources are available.

Proposed PVEH design

The overall size of the design is 196 mm length, 60 mm width, and 1 mm thickness. The circuit of six bimorph PZT-5H (40 mm x 10 mm x 0.2 mm) is a parallel connection with 90 kΩ (optimum load resistor).

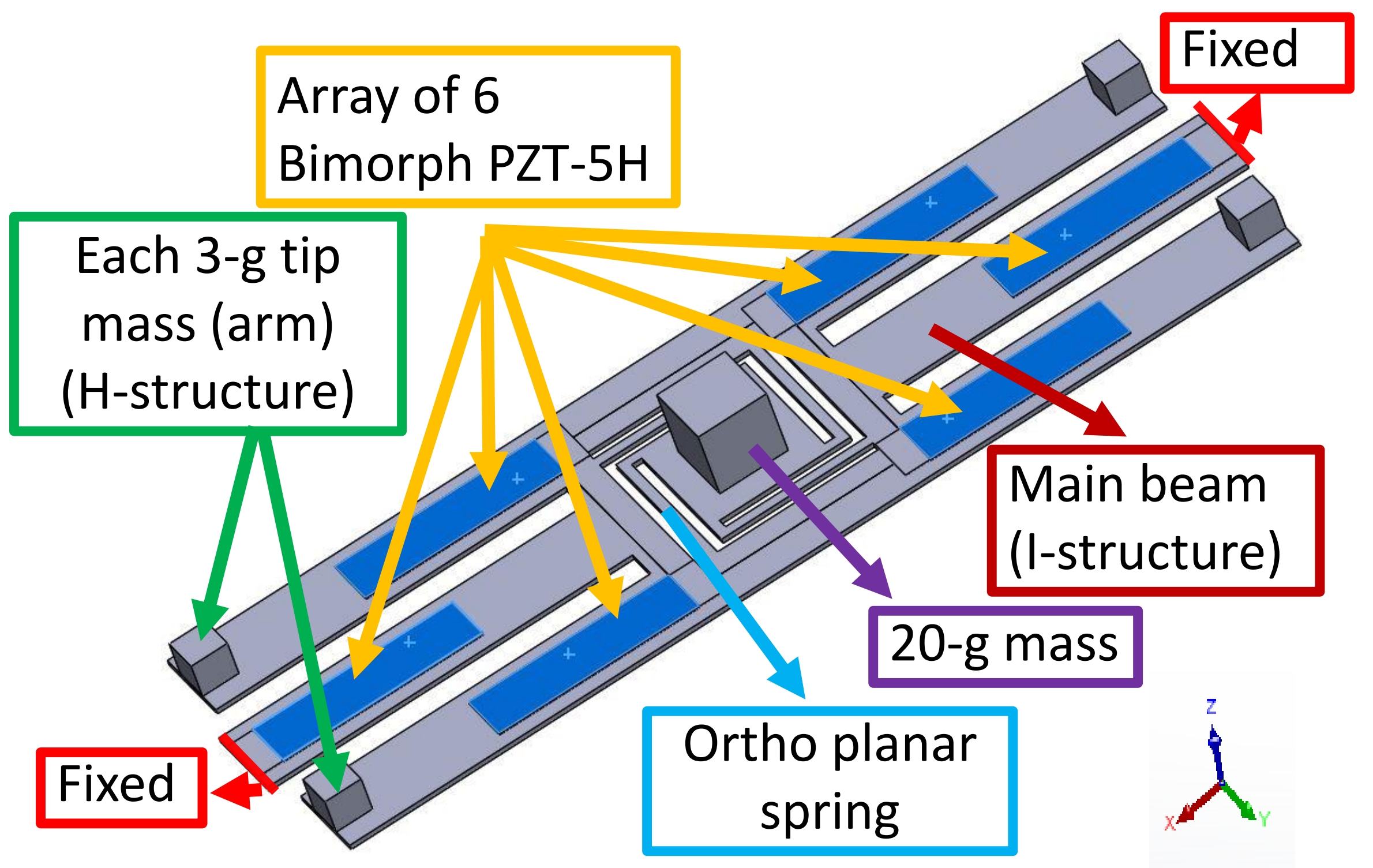


Figure. 1. Schematic diagram of the proposed harvester.

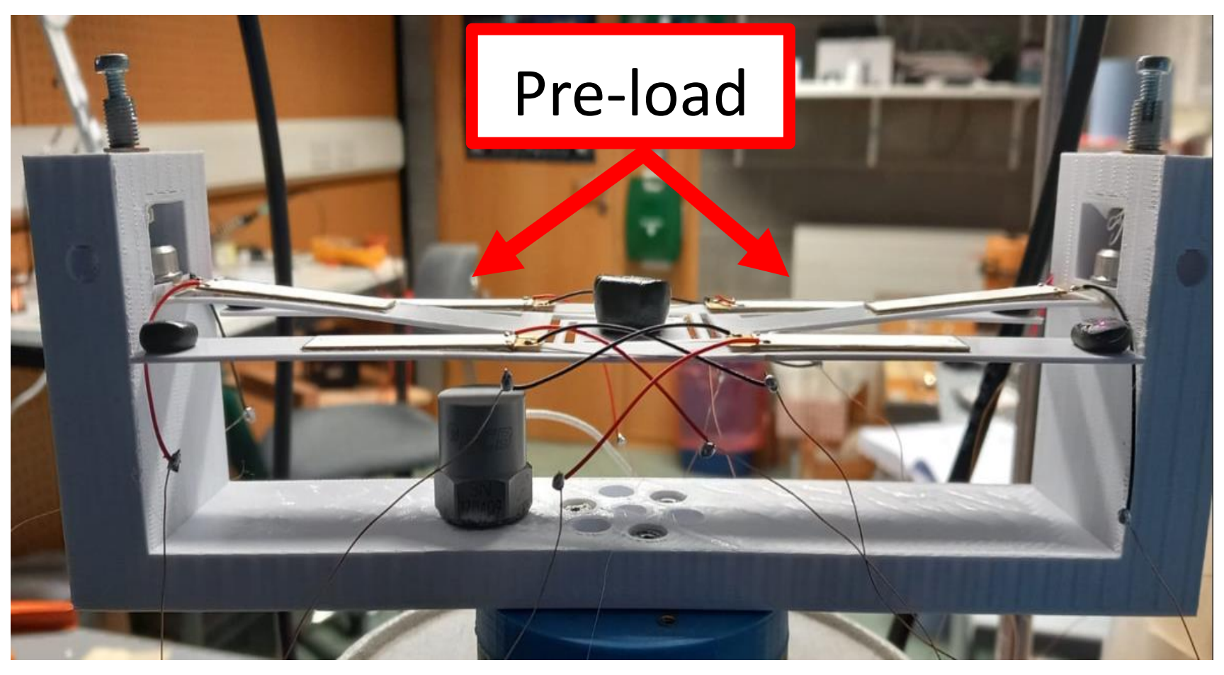


Figure. 2. The side view of the harvester (experimentation).

Mode shape analysis of the harvester

Finite element analysis (FEA) using COMSOL Multiphysics was carried out to determine the mode shape of the harvester.

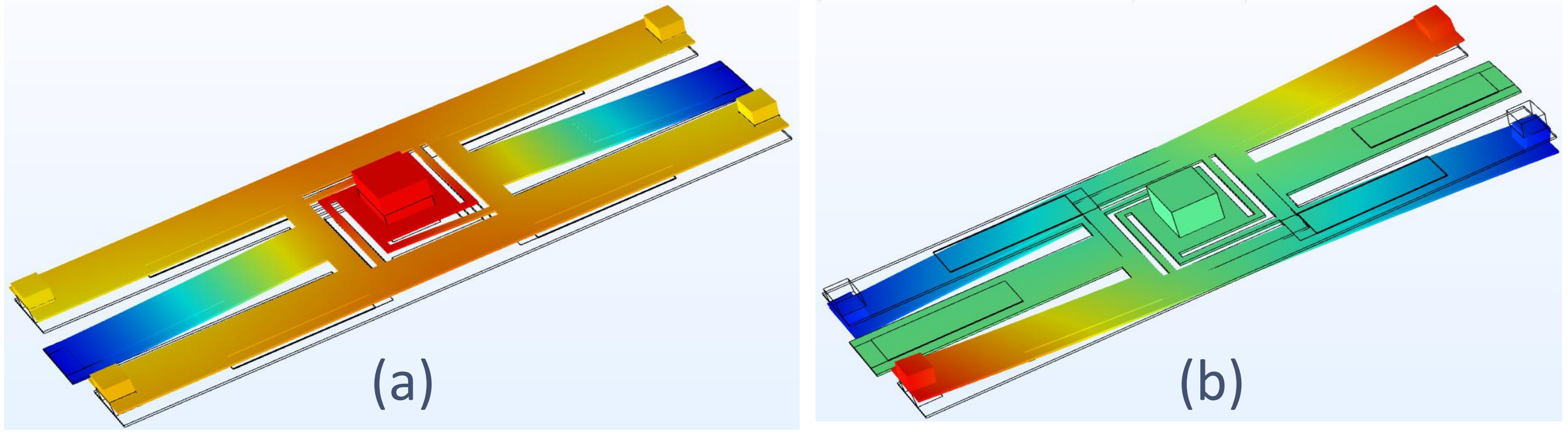


Figure. 3. The mode shape for the harvester at (a) 9.7 Hz, (b) 13.3 Hz.

Peak output power of the PVEH under harmonic excitation

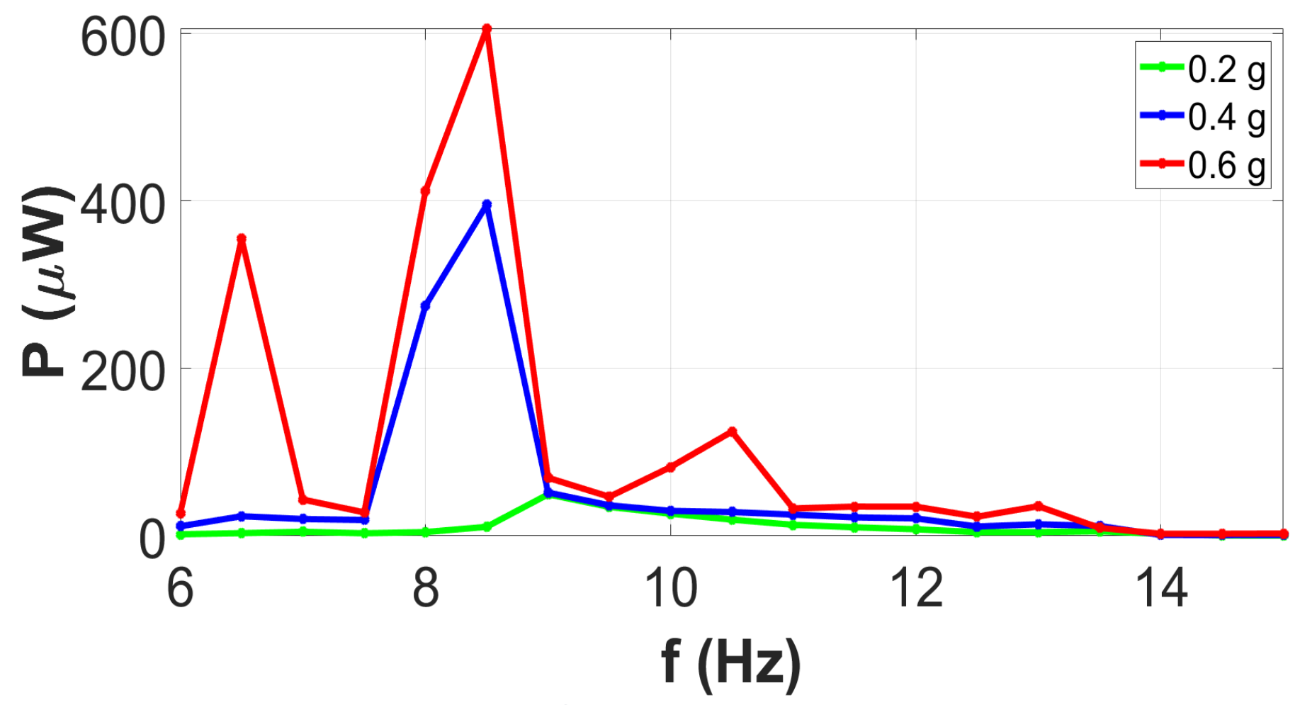
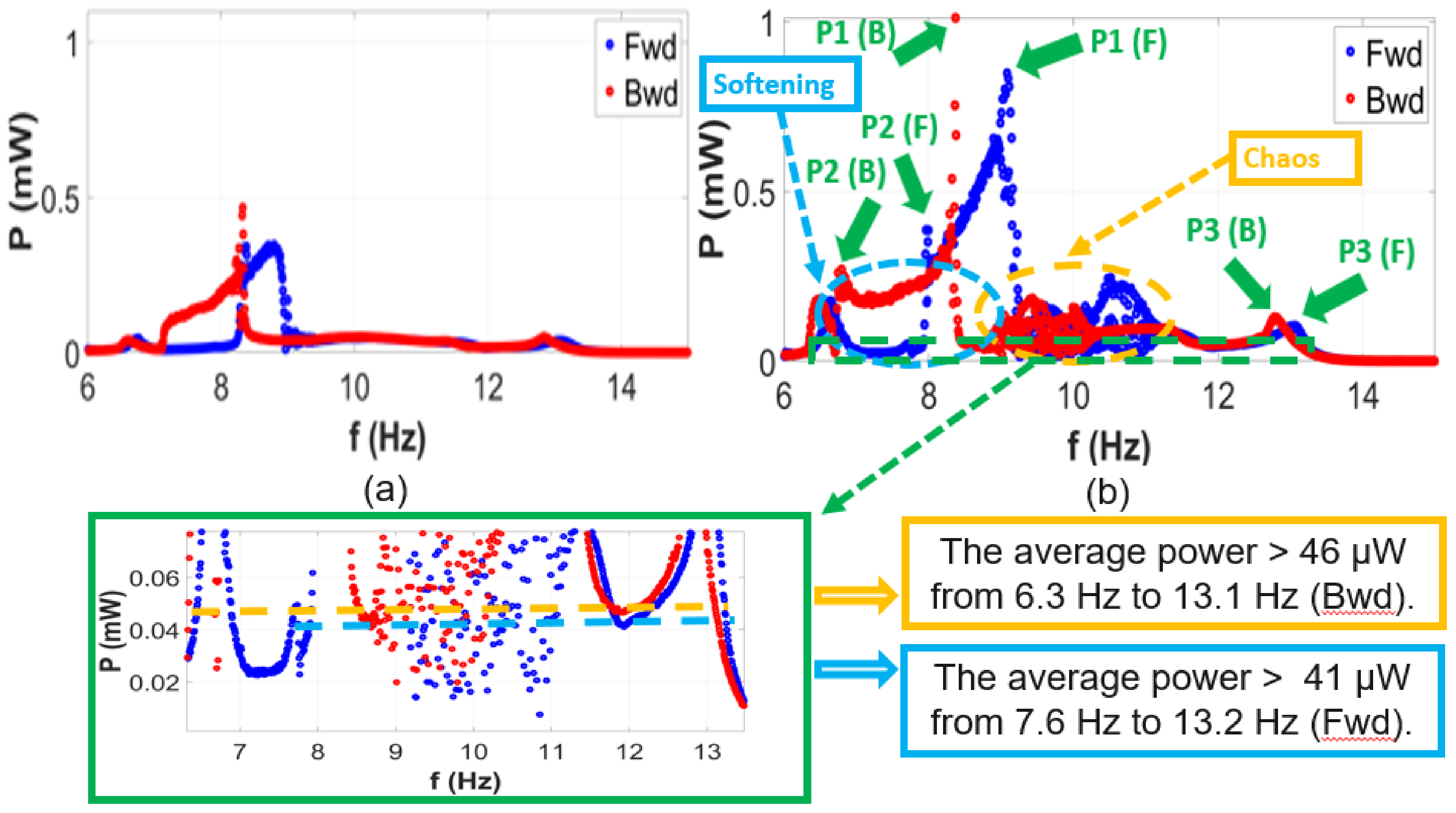


Figure. 4. The peak power frequency response curve under harmonic excitation amplitude of 0.2 g, 0.4 g, and 0.6 g (g = 9.81 m/s^2) in the z axis.

Peak output power of the PVEH under sine sweep excitation



The average power > 46 µW from 6.3 Hz to 13.1 Hz (Bwd).

The average power > 41 µW from 7.6 Hz to 13.2 Hz (Fwd).

Figure. 5. The peak power frequency response curve under forward (Fwd) and backward (Bwd) sine sweep amplitude of: (a) 0.4 g, and (b) 0.6 g.

Table 1. Summary of the peak power and half power bandwidth under 0.6 g

Sweeps	a (g)	f1 (Hz)	P1 (mW)	f2 (Hz)	P2 (mW)	-3 dB bandwidth P2 (Hz)	f3 (Hz)	P3 (mW)	-3 dB bandwidth P3 (Hz)
Fwd	0.6	9	0.84	7.9	0.38	1.3	13	0.1	0.92
Bwd		8.3	1.01	6.7	0.26	2.02	12.7	0.12	0.64

Conclusions

The FEA and experimentation of the PVEH design were performed to determine its mechanical and electrical behaviour. The harvester exhibits a softening nonlinearity and chaotic manner, which improve its output power and bandwidth. The prototype not only exhibits multiple peaks under harmonic excitation, but also generates a maximum power up to 1.01 mW at the first resonance under a sine sweep amplitude of 0.6 g. Moreover, the PVEH can generate power greater than 46 µW over a 6.8 Hz bandwidth (from 6.3 Hz to 13.1 Hz). Interestingly, the prototype shows chaotic behaviour from 8.7 Hz to 11.4 Hz, that increases the performance of the harvester with a maximum peak power of 0.24 mW. The harvester is suitable for scavenging low-frequency (sub 15 Hz) range and broadband ambient vibration energy for powering IoT sensors.

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