Design, Simulation and Optimization of Bimorph Piezoelectric Energy Harvester

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Introduction: Sustainable power generation is the key factor towards successful device miniaturization. Built in energy harvesters is a popular approach for small wireless devices. For energy devices to yield optimum results it is important that their design configurations maximize the level of power transfer. The main objective is to find parameters that give lowest resonant frequency and highest output power.

Computational Methods: The model in COMSOL is analyzed by making variations in load resistance, width and length of piezoelectric plate. The power generated depends on the resonant frequency and the load resistance by the expression:

$$P = V_{rect}\left(\frac{2\alpha}{\frac{\pi}{2}+RC_p\omega_p} + \frac{\frac{\pi}{2}+RC_p\omega_r}{\alpha R}\right) \quad (1)$$

Which gives us :

$$P = \frac{V_{rect}}{R} \quad (2)$$

The power harvester consists of a piezoelectric bimorph clamped at one end with a proof mass mounted on the other end. The bimorph has a grounded electrode embedded within it and two electrodes on the exterior surfaces of the cantilever beam.

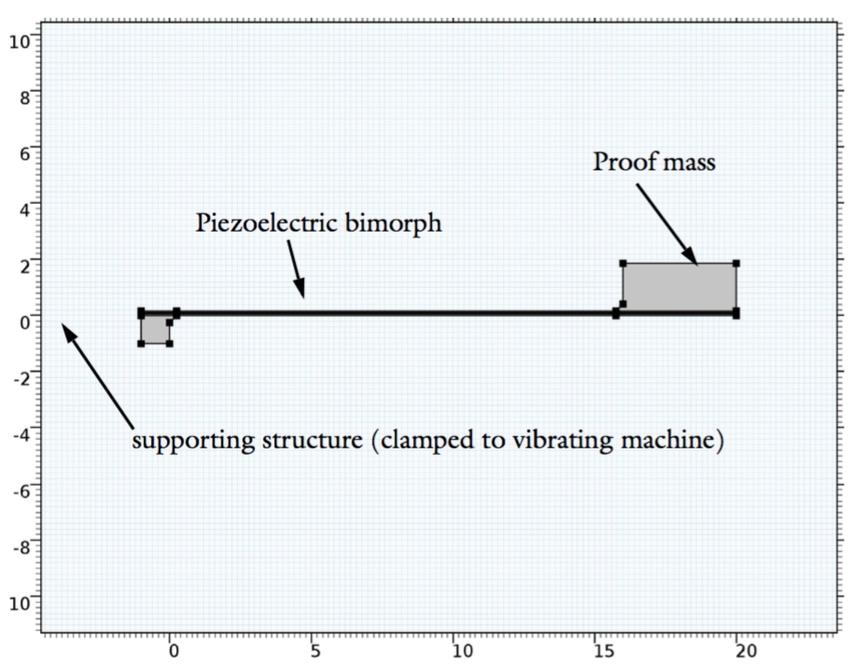

Figure 1 – Configuration of bimorph piezoelectric harvester in COMSOL

Load resistance	12 kΩ
Width of piezo plate	14 mm
Length of piezo plate	21 mm
Proof mass dimensions	4 mm x 1.7 mm

Table 1 – Initial values of the parameters

Results: The parameters varied are Load resistance , width of piezo plate, length of piezo plate and all other values are kept constant. Table 2 , table 3 and table 4 shows the effect of the variation of these parameters on the resonant frequency and the electrical power output.

Exp Run	Load Resistance (kΩ)	Voltage (V)	Resonant frequency (Hz)	Mechanical power (mW)	Electrical power (mW)
1	6	4.85	74.5	1.955	1.995
2	8	4.975	75	1.55	1.57
3	10	5.15	75	1.34	1.36
4	12	5.395	75.5	1.3	1.3
5	14	5.639	76	1.2	1.2
6	16	6	76.5	1.089	1.1
7	18	6.2	77	1.09	1.09
8	20	6.6	77.5	1.05	1.07

Table 2 – Variation of Output parameters with load resistance

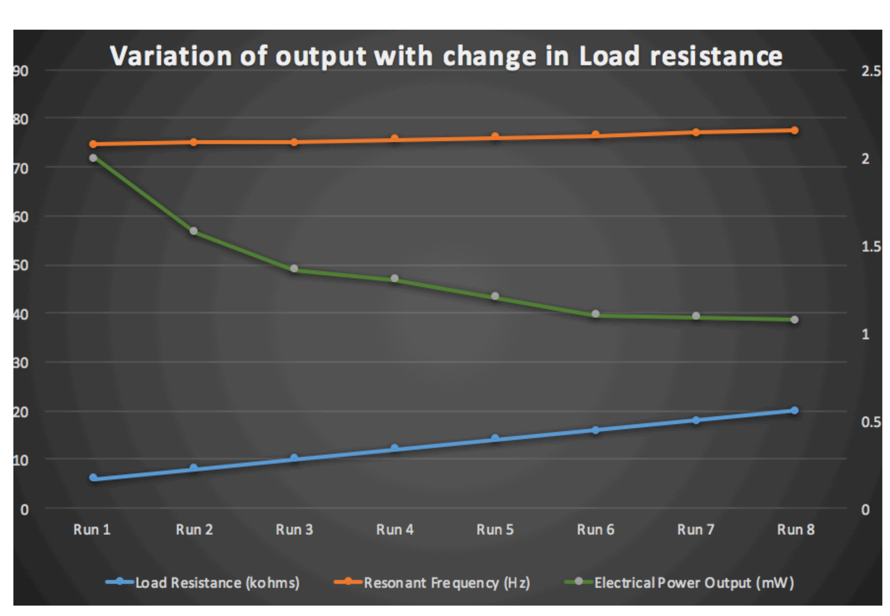

Figure 2 –Graph showing variation of Output parameters with load resistance

Table 2 shows that resonant frequency is directly proportional to the load resistance and we have the lowest value of power output with the highest load resistance which verifies the relation in equation 2 above. The green line in the graph shows the inverse relation between the load resistance and the output power. This can be an important parameter that can be used during fabrication. Figure 4 shows the simulated results output for experiment run 1 of table 2.

Exp Run	Width of piezo-plate (mm)	Voltage (V)	Resonant frequency (Hz)	Mechanical power (mW)	Electrical power (mW)
1	10	5.045	75	1.06	1.076
2	11	5.13	75	1.09	1.112
3	12	5.199	75	1.125	1.4
4	13	5.3	75.5	1.165	1.185
5	14	5.395	75.5	1.215	1.228
6	16	5.662	76	1.309	1.34
7	18	5.82	76.5	1.41	1.425
8	20	6.062	76.5	1.532	1.548
9	22	6.33	77	1.67	1.688

Table 3 – Variation of Output parameters with change in width of piezo plate

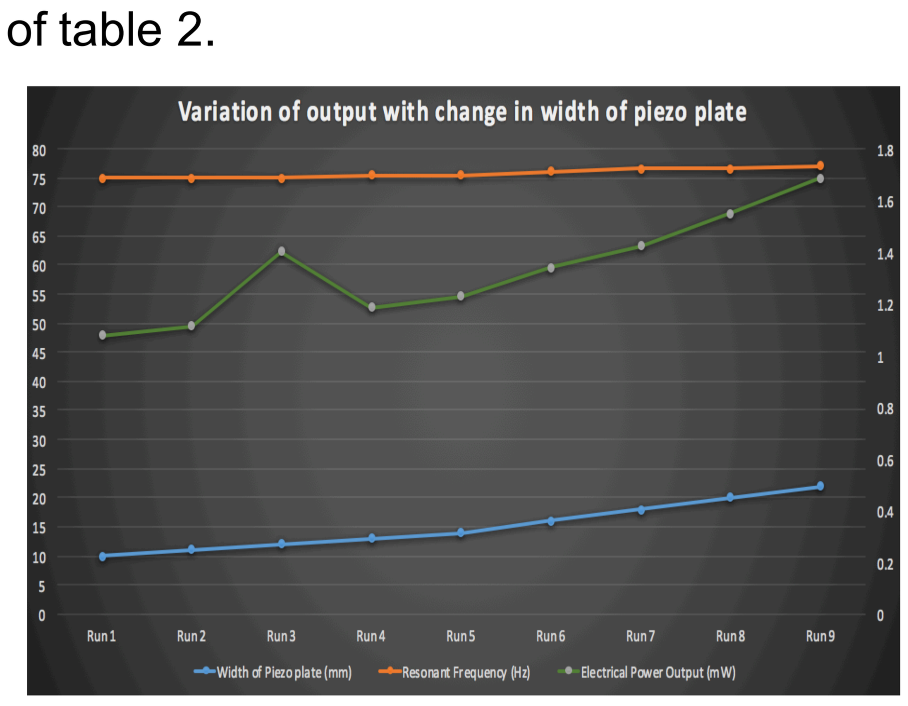

Figure 3 – Graph showing variation of output parameters with width of piezo plate

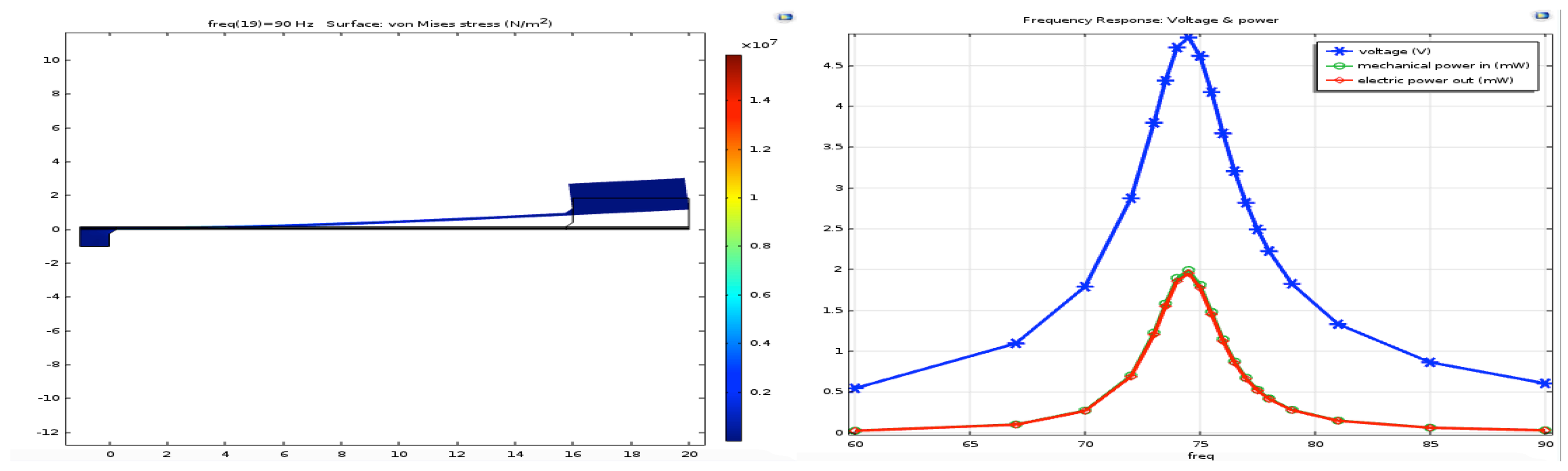

Figure 4 – Simulation results for experiment run 1 for load resistance variation

Table 3 it is observed that higher the width of the piezo plate, lesser is the damping and hence a higher resonant frequency is obtained and higher power output is obtained.

Taguchi orthogonal array is used to obtain the optimum values of the output parameters with the optimum combinations of input parameters as shown in table 4 and figure 5.

Exp. Run	Load Resistance (kΩ)	Width of piezo plate (mm)	Length of piezo plate (mm)	L/W ratio	Voltage (V)	Resonant Frequency (Hz)	Mechanical Power (mW)	Electrical Power (mW)
1	6	13	19	1.4615	3.915	90	1.279	1.305
2	7	13	19	1.4615	4.14	90	1.225	1.249
3	8	12	23	1.9167	2.494	60	0.389	0.397
4	9	16	23	1.4375	3.255	67	0.595	0.602
5	10	17	20	1.1765	4.655	81	1.081	1.096
6	11	17	18	1.0588	4.68	100	0.985	1.01
7	12	16	20	1.2500	4.663	81	0.909	0.915
8	13	15	21	1.4000	5.63	76	1.22	1.23
9	14	15	22	1.4667	6.06	70	1.31	1.326
10	15	14	22	1.5714	6.05	70	1.22	1.24
11	16	14	21	1.5000	5.91	76.5	1.09	1.1
12	17	12	18	1.5000	4.745	100	0.663	0.67

Table 4 – Taguchi Orthogonal array showing the variation of output parameters with optimum combination of input parameters.

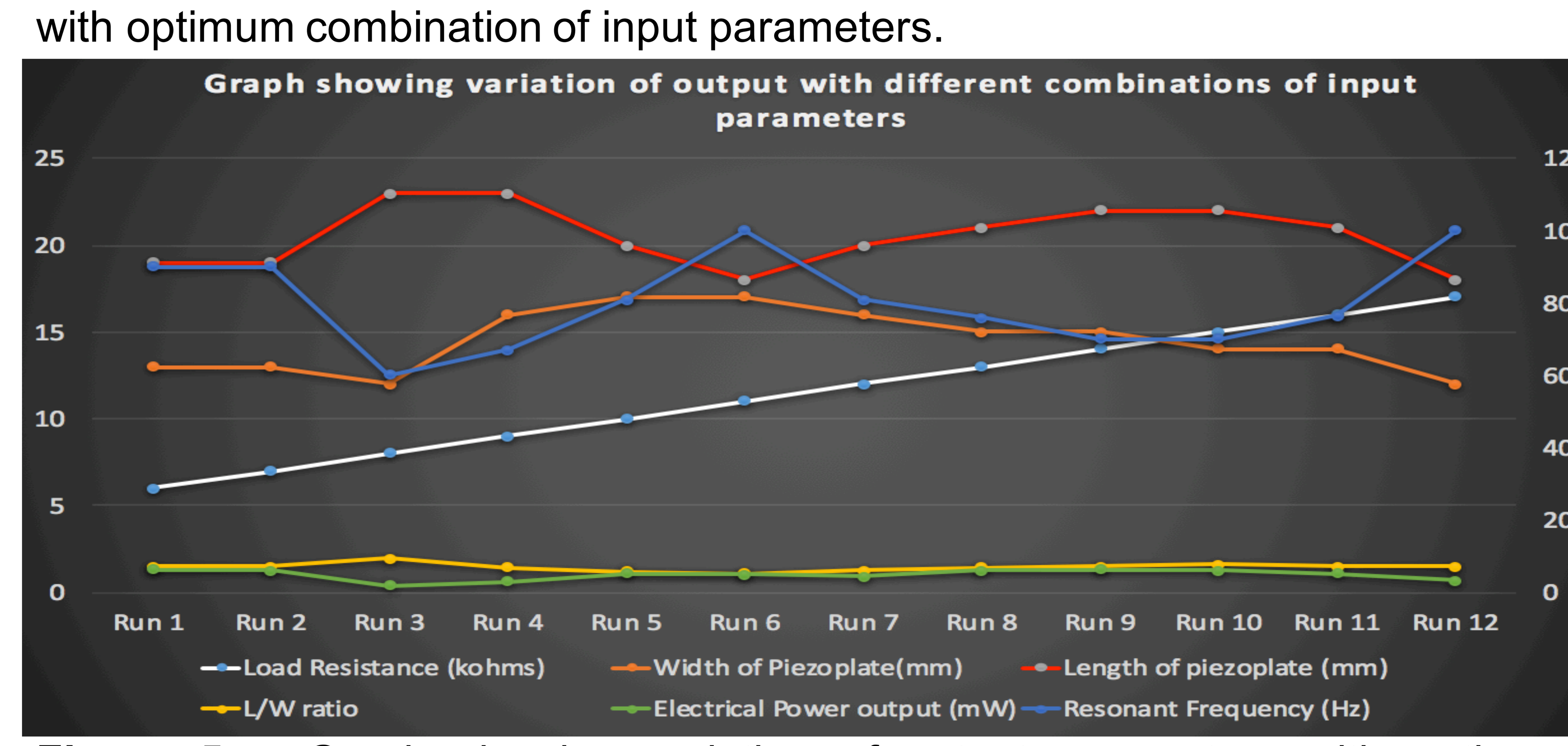

Figure 5 – Graph showing variation of output parameters with optimum combinations of the input parameters

From the readings of table 4 it can be observed that the electrical power output is maximum value of 1.326 mW (marked yellow) when the voltage is maximum and load resistance is towards the higher scale at a low scale resonant frequency.

Conclusions: Above comparison provides the optimized parameters for best harvester design. With the proof mass being constant, load resistance variation, yields that the output power is inversely proportional to load resistance and resonant frequency is directly proportional. When the width of the piezo plate is increased, the damping factor reduces which causes a higher resonant frequency and an increase in power output. Increase in length of the piezo plate increases the damping factor and hence causes a drop in the resonant frequency and the output power. In all the cases the proof mass dimension is kept a constant and varying the proof mass dimensions along with the length and width of the piezoelectric plate might give a different output which is included in future study. Thus COMSOL simulative study emerges as the effective tool to provide confidence to designers to design time and cost effective designs.

References:

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