Multi-layer generators for power autonomy in IoT

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Contents

1. Introduction

This Report analyses and compares the different piezoelectric beam experiment iterations and capacity of piezoelectric energy harvester. To differentiate between single layer and multilayer generator, we provide a hierarchical presentation based on functional analysis. The single layer and multilayer generators look similar but the outcomes might be completely different. Definitions of topologies, architectures and techniques on the basis of this hierarchical presentation is given in this report.

We then presented the comparison of the conditions for each iteration and about its power flow from an external vibration source to an electrical load, along with the detailed mathematical review in this report.

The general idea is to power an electronic device using the power generated by the piezoelectric beam and to get benefit from its power producing characteristics.

2. AIM

Comparison of multi-layer generators and single-layer power generator is the actual idea of this report. This report holds a deep significance in Energy harvesting systems. Once we know that the multi-layer sensor is capable of producing significant power to operate small electronic devices, they can used to power those devices without any external power supply or batteries. The main reason for the comparison is to check whether the multilayer is really capable of producing higher power when compared with the single-layer power generator.

3. Components

3.1. Beam

A piezoelectric harvester is usually a cantilever beam located on a vibrating shake with piezo-ceramic layers. The dynamic strain produced in the piezo-ceramic layers produces an alternating voltage output across the electrodes covering the piezo-ceramic layers as a consequence of beam vibration.

The impedance which we measure is the voltage applied, electrical impedance is the indicator of the opposition that a circuit provides to a current.

3.2. Weights

The weights are added to the beam in the form of magnets to obtain the different results and to make comparisons.

3.3. MFIA

MFIA instrument, is very accurate impedance analyzer with 0.05 percent precision is defined between 1 mHz and 500 kHz,

3.4. LABONE user interface

Like any other software interface. For downloading the sampled points, we have click on the cloud icon button below the graphs, the data gets downloaded in CSV Format.

4. Circuit diagram

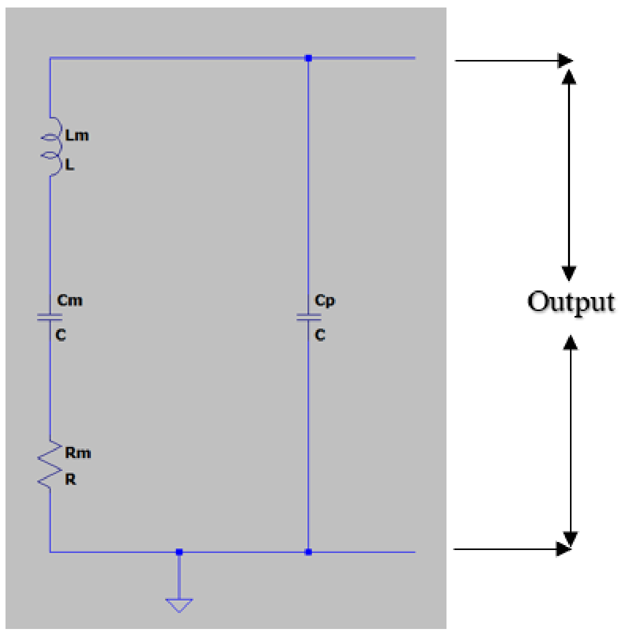
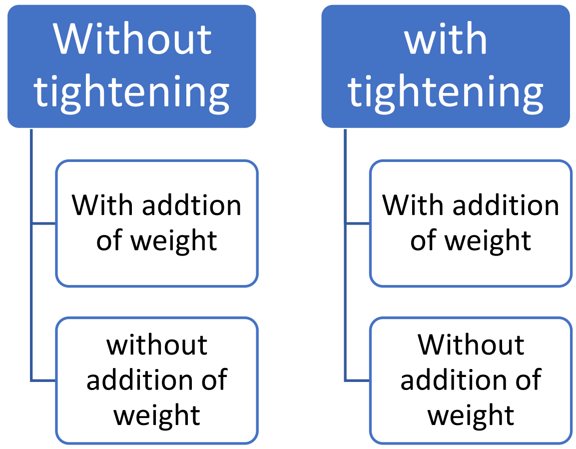


Fig 4.1: RLC circuit for the system

5. MFIA results

The details given below are the results obtained from the MFIA impedance analyser. The results were taken into two categories with two variation for each. The first one is without tightening and the second one is with tightening by the screw. The variation being the before and after addition of weight. This experiment was carried out to figure out the differences between these two. We took the average of five readings to obtain a better view of the results with more accuracy.



5.1. Without Tightening

The piezoelectric beam is suspended on the support bar by the screws with and without adding weight. Their differences are graphed below and explained.

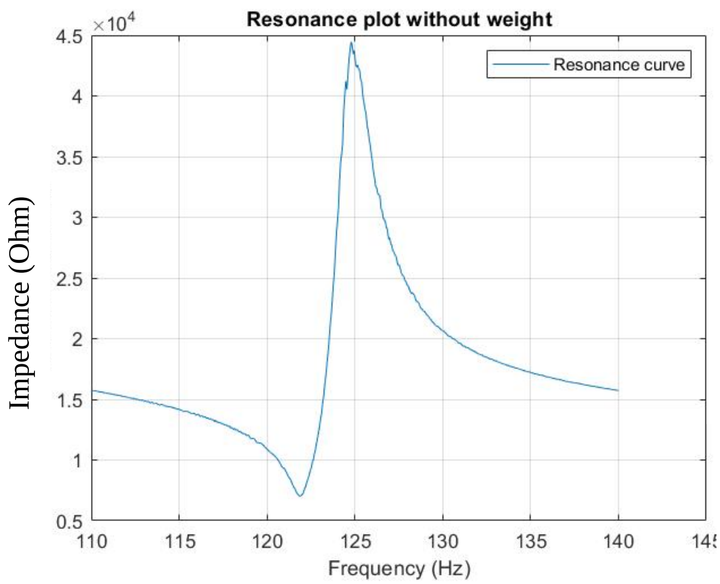


Fig 5.1.1: Without addition of weight

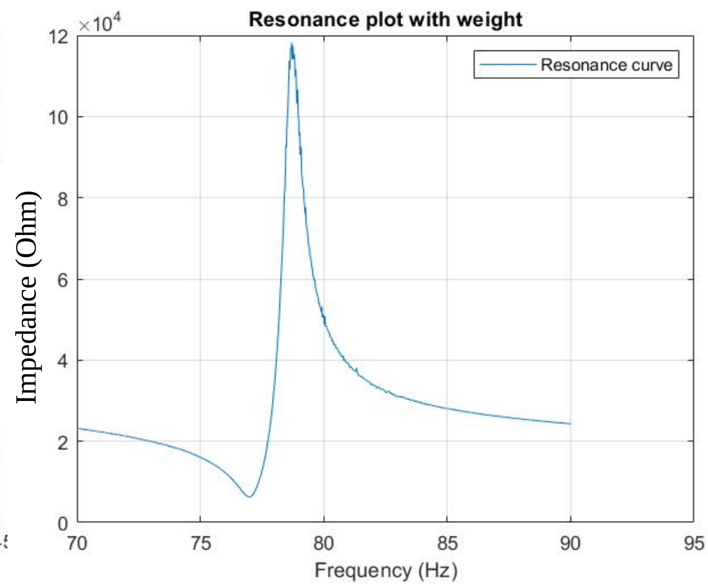
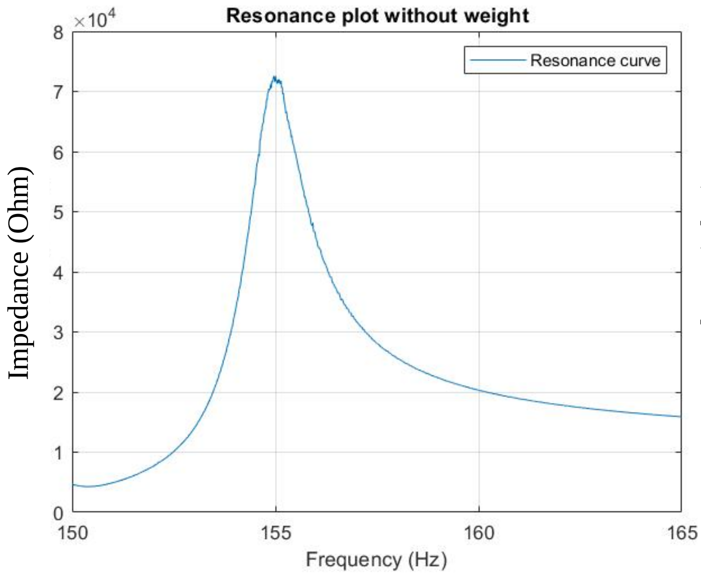


Fig 5.1.2: With the addition of weight

The frequency range is set between 50 Hz to 150 Hz for both the iterations. And the graphs were obtained by fixing the sampling points to 1000. Here on the addition of weight (Fig 5.1.2) the resonance curve is found much earlier in between 70 Hz to 95 Hz, whereas in case of no weight the resonance is found between 110 Hz to 145 Hz. Also, the major difference in the resonance values is also seen in between them.

5.2. With Tightening



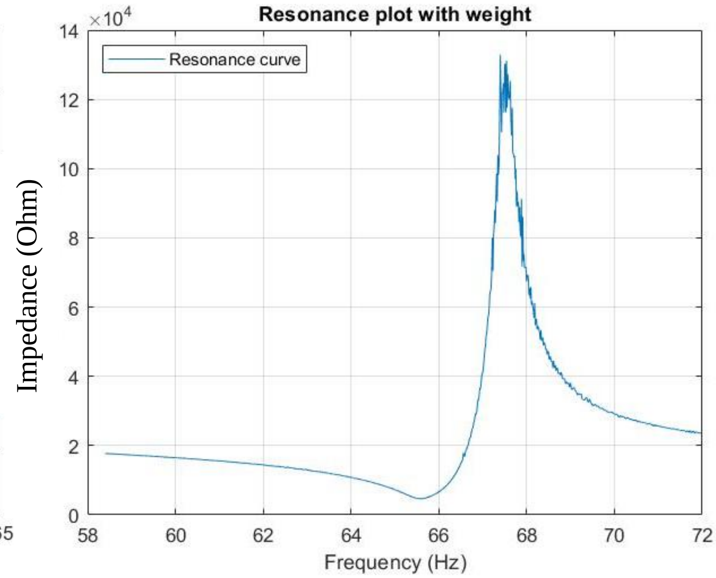


Fig 5.2.1: Without addition of weight

Fig 5.2.2: With the addition of weight

With proper tightening, we were able to get a sharp resonance, which are detailed in the graph. With addition of weight in this case, the resonance was found much earlier than the previous case (resonance with weight and improper tightening), which is usual.

5.3. Parasitic Resonance

Reason to find the major difference between these two categories is, in this case of improper tightening, we came across a huge parasitic resonance (circled in red in Fig 5.3.1). The beam vibrates in all direction and subjected to noise (which led to the parasitic resonance).

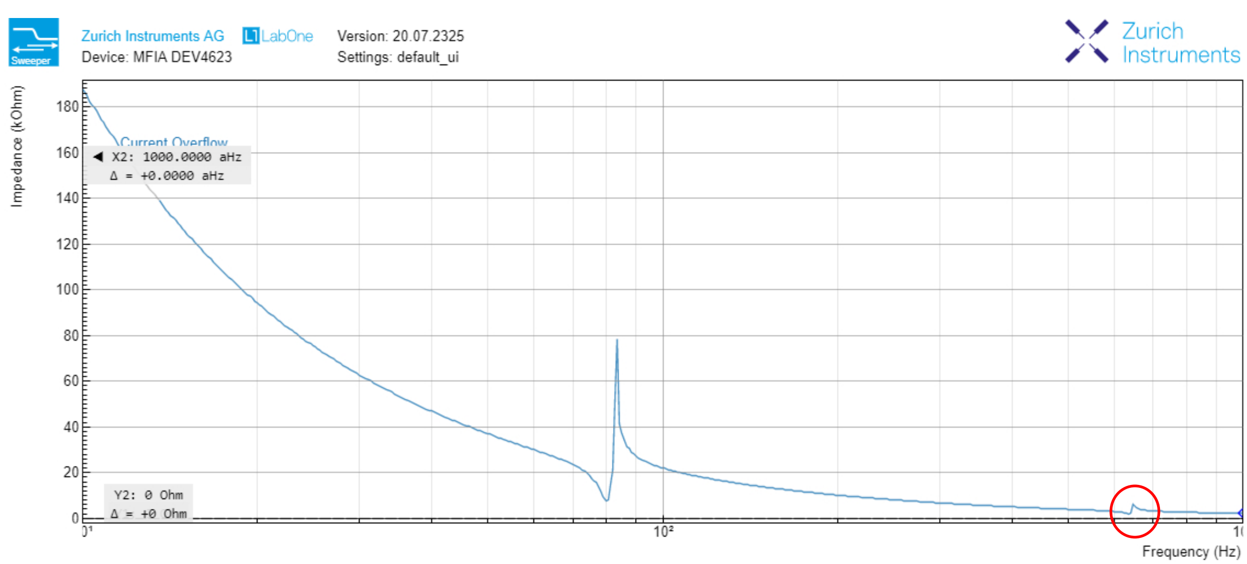


Fig 5.3.1: Parasitic resonance (circled in red) due to improper tightening

Now after tightening the screws, it arrested the vibration motion of the beam in all direction. Only Up and Down motion of the beam was permitted. No random vibrations of the beam are allowed now.

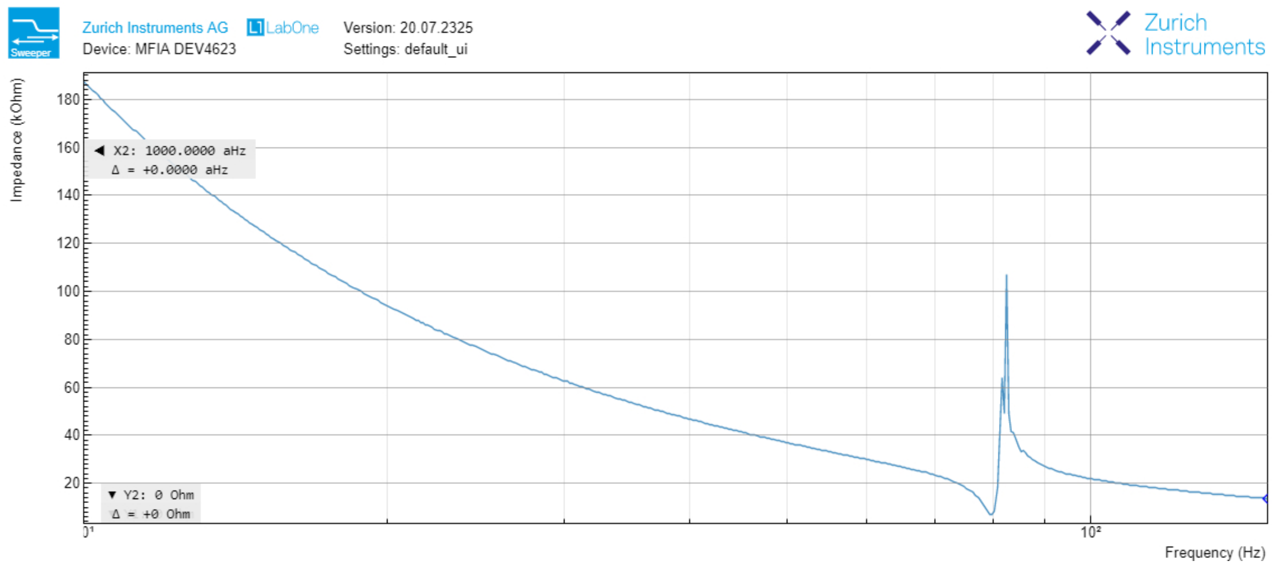


Fig 5.3.2: Parasitic resonance arrested after proper tightening

6. Simulation Design

Now we are simulating the model in the MATLAB to compare the results obtained with that of the experimental results. This is done to see whether the results obtained through the theoretical calculations matches with that of the experimental results. Even though the assumption of linearity is sometimes debatable, it remains a reasonable and common basis to compare the performance of electronic circuits. The simulation model is designed based on the above circuit. As we know the impedance of the components in the circuits are:

$$C = \frac{1}{j\omega C_m}; \quad L = j\omega L_m; \quad R = R_m; \quad Cp = \frac{1}{j\omega C_p}$$

The impedance Z of the C_m, L_m, R_m is given by the equation:

$$Z = C + L + R \qquad (1)$$

Now the values of components are:

$$L_m = \frac{1}{{k_m}^2 * {\omega_o}^2 * C_p} \; ; \;\; C_m = C_p {K_m}^2 \; ; \;\; R_m = \frac{1}{{k_m}^2 * Q * \omega_o * C_p}$$

We now substitute the values of L_m, C_m and R_m in the (1) to obtain the impedance Z. The obtained equation is:

$$Z = \frac{1}{{k_m}^2 * Q * \omega_o * C_p} + \frac{1}{j\omega * C_p * {K_m}^2} + j\omega \frac{1}{{k_m}^2 * {\omega_o}^2 * C_p} \qquad (2)$$

Now we find the total impedance of the circuit:

$$Z_{tot} = \frac{Z}{1 + j\omega * C_p * Z} \qquad (3)$$

Now we substitute the (2) in (3) and we the get the Z_{tot}. For easier simplification we use the MATLAB function called **simplify( )** that simplifies the equation for us. The obtained simplified equation is:

$$Z_{tot} = \frac{jQ\omega^2 + \omega * \omega_o - jQ\omega_o}{C_p * \omega \left(Q * {\omega_o}^2 - Q * \omega^2 + {k_m}^2 * Q * {\omega_o}^2 + j\omega * \omega_o\right)} \qquad (4)$$

Since after solving we obtained the equation (4). Now we have four unknown variables K_m^2, Q, C_p, ω_o. the values of ω is the range we have chosen from the experimental result where we found the huge resonance.

Here we now substitute some values to the variables like spring constant (K), Quality Factor (Q), angular frequency (ω_o) and try to plot the result and will compare it with the experimental result. Let's substitute $K_m^2 = 0.05$ as this the largest coupling coefficient for most of the systems except some reach higher. The Quality factor Q = 40 and C_p = 100*e-9 and angular frequency $\omega_o = 240*\pi$. The natural frequency ω will be the same as the practical result range.

Since the equation is not a linear equation, we use the function called **lsqnonlin( )** in MATLAB to solve the nonlinear least-squares (nonlinear data-fitting) problems.

7. Simulation Results

Now let's compare the results of the experiment with that of the simulation result. The variations between them are also explained. Let go in the same order as the above MIFA results part.

7.1. Without Tightening

Now on seeing the resonance plots we can clearly say that without weight (Fig 7.1.1) the theoretical

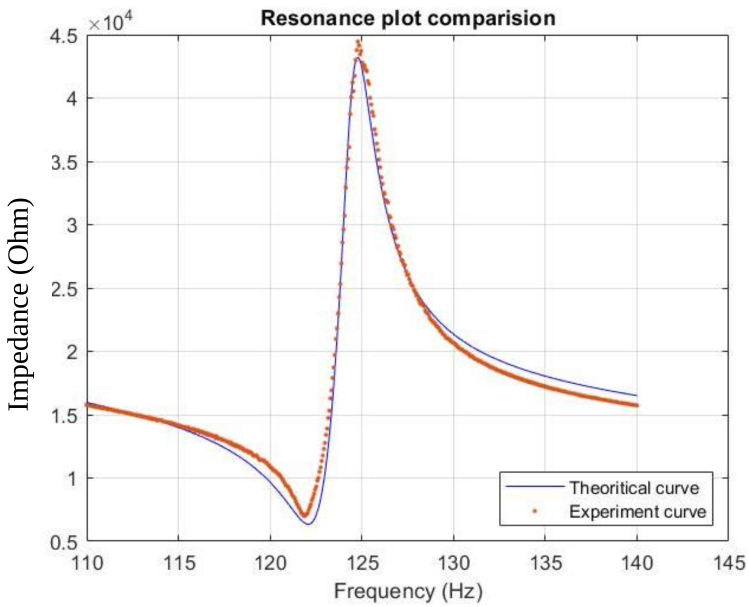


Fig 7.1.1: Without addition of weight

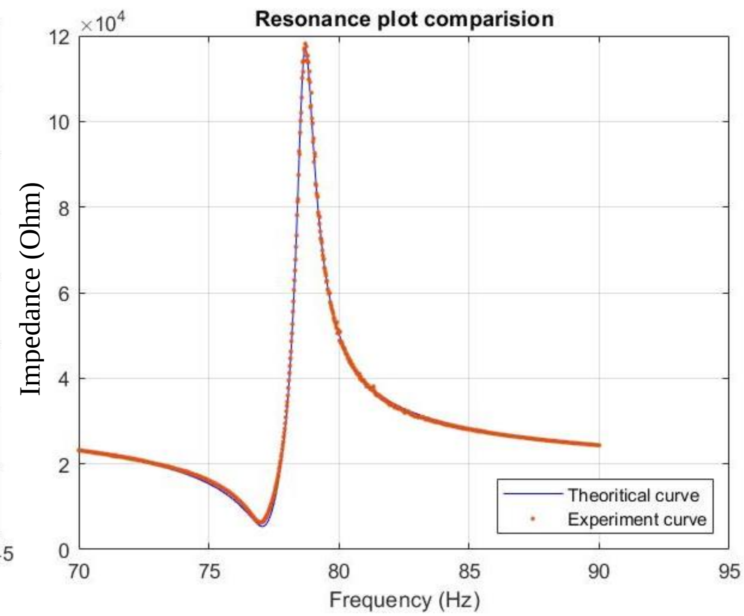
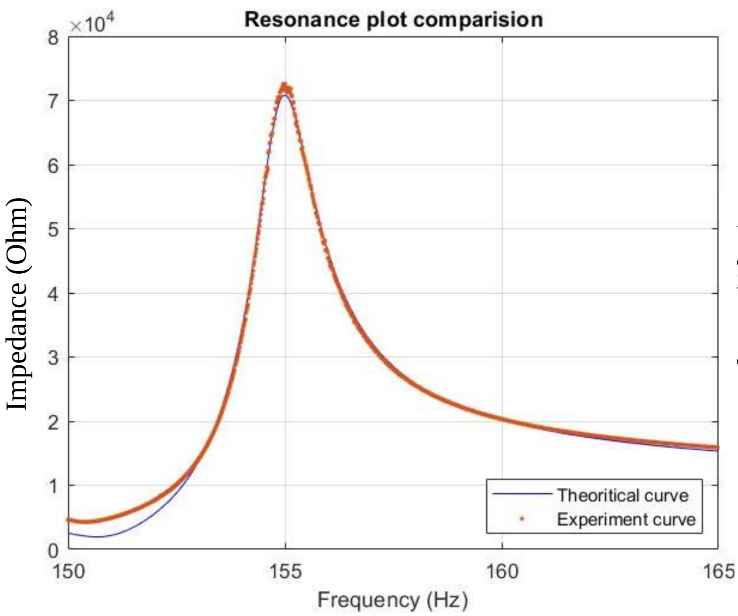


Fig 7.1.2: With addition of weight

curve Is not matching exactly with that of the experiment curve. This is because of the different vibrations that happens in all directions. On adding the weight (Fig 7.1.2), it is evident that the curve almost matches with the experiment. This is because the weight has reduced the vibrations in all directions a little but not completely, instead vibration is high on the direction of the weight is suspended.

7.2. With Tightening

Let’s now look at the results comparison after tightening the screws.



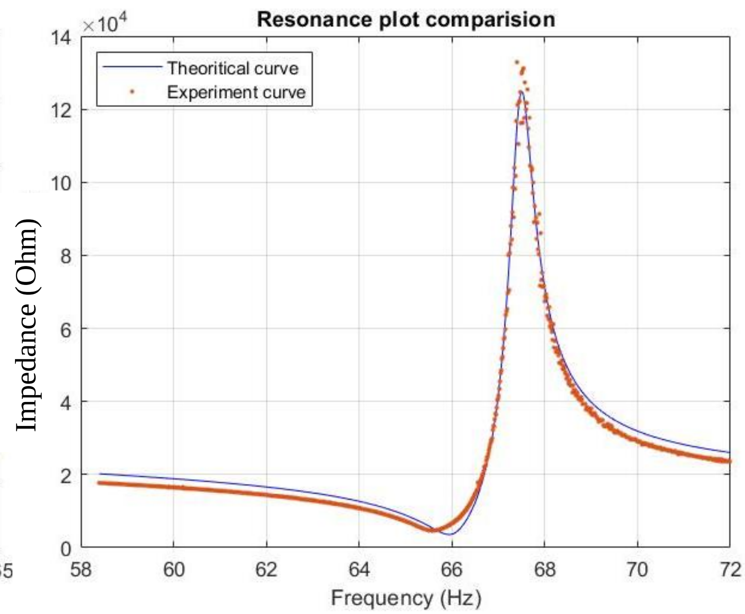


Fig 7.2.1: Without addition of weight

Fig 7.2.2: with addition of weight

Here we can notice that the resonance curve has appeared in different range and also the resonance peak for the curve with the weight (Fig 7.2.2) is sharper and has high resonance whereas for the curve with no weight (Fig 7.2.1) has low resonance. As we can see in Fig 7.2.2 the resonance peak for the theoretical curve is less compared to that of the experimental curve. This is due to the noise or inaccurate measurement present in the system. This can be reduced and we can obtain an almost accurate match by taking the average of readings with n number of samples.

7.3. Observation

On comparing the different results obtained, we can clearly see that on addition of weight gives a better resonance than without adding weight. And if the beam is tightly screwed to the base, the result is much better. When we look at the result in Fig 5.1.2 and 5.2.2, we can notice even though on addition of the weight the curve has difference just by tightening the beam with the base. We can see after tightening the resonance is obtained within 60 Hz and 72 Hz. Whereas in case of improper tightening the resonance is observed between 70 Hz and 90 Hz. As previously said, the vibration of the beam in different angles causes the parasitic resonance due to improper tightening.

Then when we compare the simulation result with that of the experimental result, we can notice that from the Fig 7.1.1 and Fig 7.1.2, it is clear that on adding weight (Fig 7.1.2) it looks like we obtained a good result as the theoretical and experimental results match together. But it won’t be the same in all situations since it is not tightened well, the resonance will vary for different iterations at different situations. Also, in the Fig 7.2.1 and Fig 7.2.2 we can say that the resonance is high with addition of weight. This is because of the weight added to the tip of the beam on the end opposite to that of the screwed end, the weight makes the beam to vibrate further and this results in higher resonance.

Even though the above obtained results are done with the 300mV as test source voltage, experiments are done with different test voltages and the results are obtained accordingly. Also, the output current when measured is found to be more when the weight is added with the beam than without any weight. Also, to obtain an accurate or near to accurate result, taking the average of the n number of readings will help.

7.4. Comparison table

Even though the above figures have given us a visual difference between the results, but the comparison within the parameters during different iterations will give us a better understanding of the experiment and their difference in the results. A comparison table and their differences in percentage has been given to get a better view of the simulation results.

Here we have compared the differences in the four different parameters (k_m^2, ω_o, C_p, Q) with each different iteration we have performed i.e. Without tightening (Without weight and with weight) and with tightening (Without weight and with weight)

Table 7.4.1: Comparison of Parameters

Type	K_m^2	ω_o	C_p	Q
Starting values	0.05	240π	100*e-9	40
Without tightening without weight	0.0335	122.4165	4.8534*e-7	68.0068
Without tightening with weight	0.0397	77.1272	5.0701*e-7	114.7989
With tightening without weight	0.052	150.7799	5.4848*e-7	108.9138
With tightening with weight	0.0506	65.8	7.855*e-7	128.9676

Table 7.4.2: Difference in their comparison

Factor	**K_m^2**	**ω_o**	**C_p**	**Q**
Starting values	0.05	753.6	1*e-7	40
Without tightening without weight	Decreased by 33%	Decrease by 83.76%	Increase by 385.34%	Increase by 70.02%
Without tightening with weight	Decrease by 20.6%	Decrease by 89.77%	Increase by 407.01%	Increase by 186.99%
With tightening without weight	Increase by 4%	Decrease by 79.99%	Increase by 448.48%	Increase by 172.28%
With tightening with weight	Increase by 1.2%	Decrease by 91.27%	Increase by 685.5%	Increase by 222.42%

8. Conclusion

Thus, from the above experiments we can come to a conclusion that if the beam is tightened well with the base and with the weight suspended to the end of the beam, the piezoelectric beam will vibrate enough to produce high resonance which in turn will produce the necessary current to operate a small electric device without any external power supply. The experiment with the multilayer generator is in progress.