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An Effect of Coupling Factor on the Power Output for Electromagnetic Vibration Energy Harvester

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Introduction

- An adequate study of structural dynamic characteristic is very important as a robust method for assuring the satisfactory integrity and structural health monitoring (SHM).
- An unpredicted/unaware failure in structure may cause devastating consequences on economic, social, and human life.
- Continuous, efficient, ecofriendly, retrofit easy, cheap and autonomous powering a SHM device/sensors has been a major target of the 21st century compliant SHM devices since battery power module has some limitations with usage.
- One special power module that has over the years been used in a battery less powering of SHM sensors is the electromagnet vibration energy harvester (EVEH).

SDOF Harvester Model

- The focus in this work is on formulating sets of analytical equation for characterizing the harvester's optimum magnetic flux parameter to be used in computing the optimum coupling factor, the electromagnetic damping ratio, and the maximum resonant power of the proposed SDOF harvester model
- To properly define the harvester's resonant frequency, it is modelled as a fixed-free Single Degree of Freedom (SDOF) tip loaded beam as shown in Figure 1.

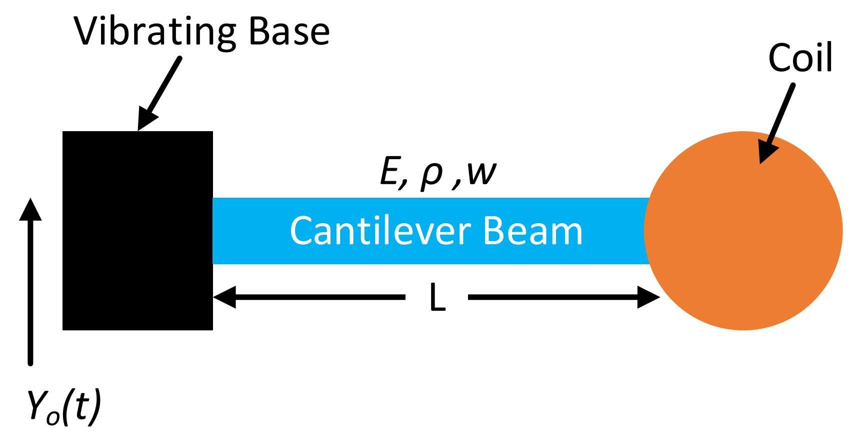

Figure 1. The vibration energy harvester modelled as a fixed-free SDOF cantilever beam with a tip coil mass fixed at its free end.

Mathematical Model

- According to the Euler Bernoulli beam theory, vertical displacement ($z_{rel}(x,t)$) for *n-th* mode can be represented as the product of the spatial/mode shape response($\varphi_n(x)$) and temporal response($\eta_n(t)$)

$$z_{rel}(x,t) = \sum_{n=1}^{\infty} \varphi_n(x)\eta_n(t) \qquad (1)$$

- ω_n is the *n-th* vibration mode's resonant frequency of the beam-mass system obtained as

$$\omega_n = \beta_n^2 \sqrt{\frac{\mathrm{EI}}{\rho A L^4}} \qquad (2)$$

where E is the Young modulus, I is the second moment of area, ρ is the density, A is the cross-sectional area, and L is the cantilever beam length.

- Equation (2) shows that the resonant frequency could be obtained as a function of the harvester's geometry and properties.

Mathematical Model

- The electromagnetic harvested power of an electromagnetic vibration energy harvester was obtained as

$$P_{Coil} = 16K^2{l_c}^2(\omega_n z)^2\left(\frac{1}{R_l + R_c}\right) \qquad (3)$$

- From equation (3), the electromagnetic damping ratio (ζ_E) was obtained as

$$\zeta_E = \frac{8K^2{l_c}^2}{m_e\omega_n}\left(\frac{1}{R_l + R_c}\right) \qquad (4)$$

- Rearranging equation (4) and making K as the subject of the formula gives:

$$K = \sqrt{m_e\omega_n\zeta_E\,(R_l + R_c)\left(\frac{1}{8l_c^2}\right)} \qquad (5)$$

- The total damping is a sum of the mechanical damping [1,2] and the electromagnetic damping .

Results and Discussion

- Figure 2 shows the variation of damping for several resonant frequencies from 10 Hz to 50 Hz in steps of 10 Hz for the proposed design geometry.

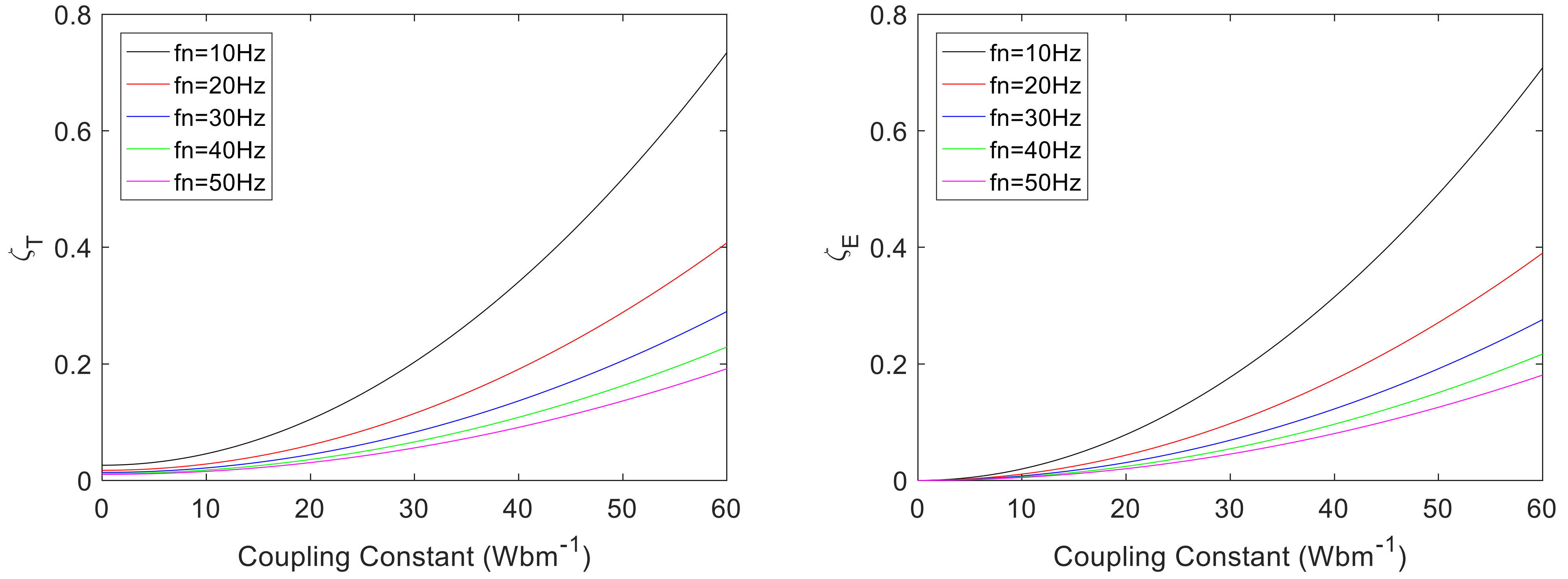

Figure 2. Comparison of the damping ratio with the coupling constant at different resonant frequencies for the total damping (left) and electromagnetic damping (right) when $R_l = 111.42\ \Omega$

Results and Discussion

- Figure 3 shows the variation of electromagnetic damping for several resonant frequencies from 10 Hz to 50 Hz in steps of 10 Hz proposed design geometry.

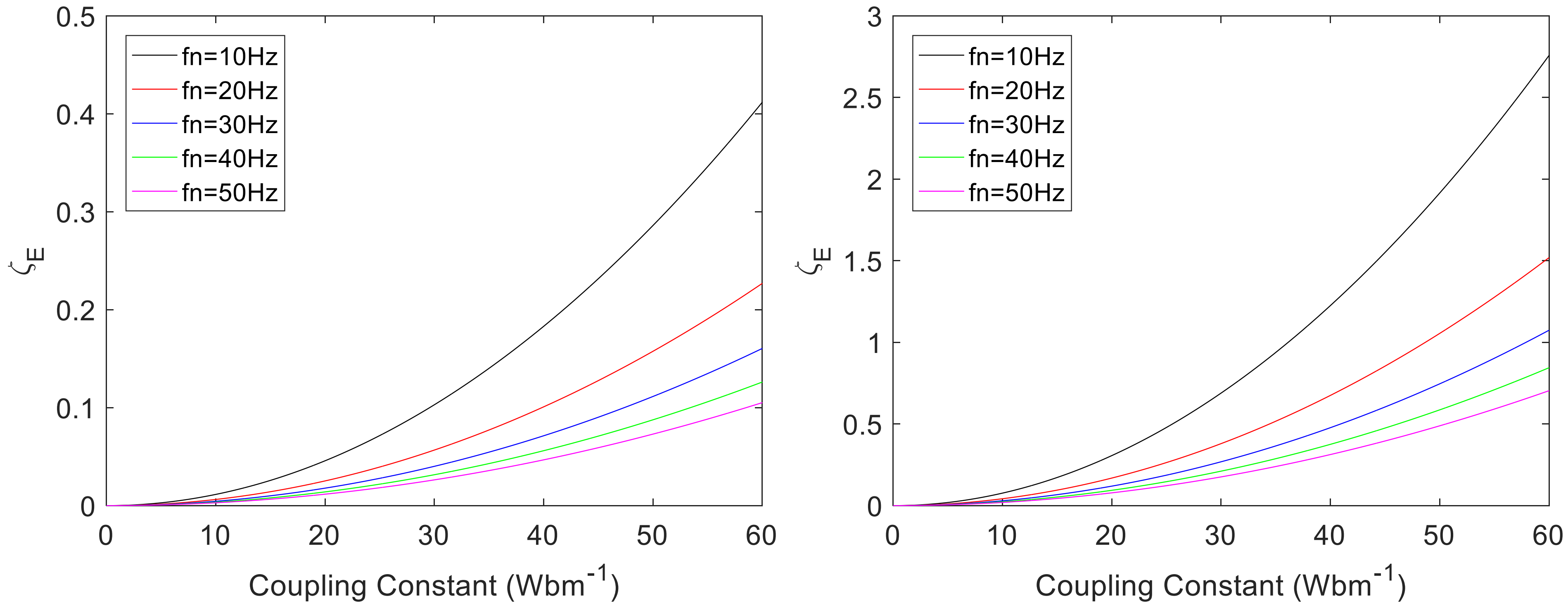

Figure 3. Comparison of the electromagnetic damping with the coupling constant at different resonant frequencies for different values of load resistance, $R_l = 200\ \Omega$ (left) and $R_l = 20\ \Omega$ (right).

Results and Discussion

- Figure 4 shows that the power harvested varies the coupling factor

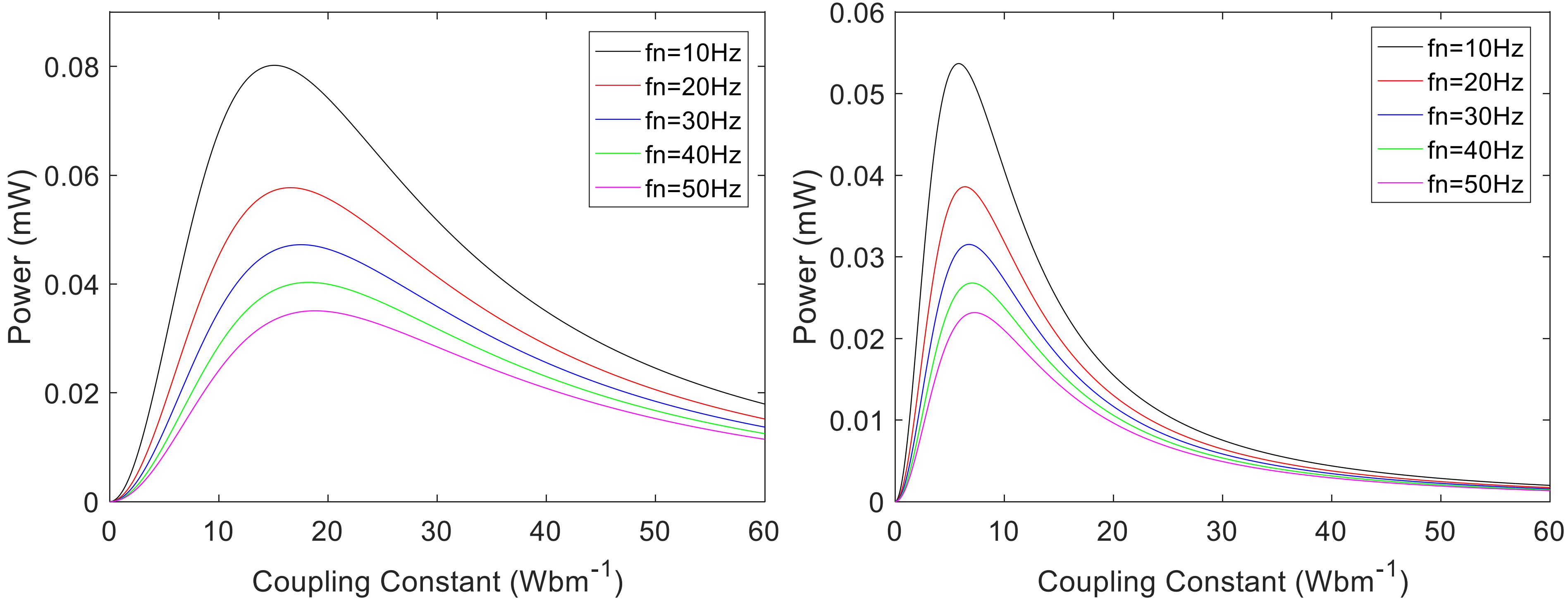

Figure 4. Power harvested against the coupling constant at different resonant frequencies for different values of load resistance, $R_l = 200\ \Omega$ (left) and $R_l = 20\ \Omega$ (right).

Results and Discussion

- From the harvester design standpoint, an accurate and precise electro-mechanical coupling in the harvester system is necessary for achieving maximum efficiency and highest harvestable power.
- Literatures [3,4] have reported that , the coupling constant (K) for the electromagnetic harvester can be expressed as

$$K = Nbc_f l_c \tag{6}$$

- Where b is the magnetic flux density; N is the number of the coil turn; c_f is the coil fill factor; and l_c is the effective length of the coil.
- Parameters N, c_f and l_c were considered fixed because it is peculiar to a specific coil design such that once the coil has been fabricated, it values cannot be altered. However, b could, hence it becomes a major parameter which could be maneuvered to achieved optimum coupling/damping value.

Conclusion

- As shown in Figure 4, a point along the power-coupling factor curve where the harvested power becomes maximum for each specific resonant frequency is the optimum power.
- This maximized point is the location where the electromagnetic damping and the coupling factor becomes optimized.
- Each maximized resonant power peak corresponds to an optimized resonant value of the flux density (b) whose optimum value could be obtained using the optimum value of K and the coil parameters $(N\ and\ l_c)$ in equation (6).
- To ensure a higher harvested resonant power is available to the sensor node, the harvester must operate at certain threshold value (20 Hz in the design proposed) and the optimum resistance of the sensors must be made as reasonably high as possible to match the harvester's optimum resonant damping ratio used during the sensor fabrication.

References

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[3] F. M. Foong, C. K. Thein, and D. Yurchenko, “A two-stage electromagnetic coupling and structural optimization for vibration energy harvesters,” *Smart Mater. Struct.*, vol. 29, no. 8, p. 85030, 2020.


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