Energy harvesting from vibration using IPMC taper cantilever beam

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1. INTRODUCTION & OBJECTIVE

In the present era of technological advancement, daily innovation requires energy to operate device, the energy requirement of these devices are very low, and can be fulfilled by capturing waste energy (such as solar energy, wind energy, vibration energy etc.) from environment. Energy harvesting is the process of trapping environmental waste energy, converting it into electrical (or same useful form) energy and storing it for future use[1].

Ionic polymer metal composites (IPMCs) are synthetic composites material that shows artificial muscle like behaviour. Ion migration and redistribution creates bending deformation in IPMCs under the application of electric field or voltage, alternatively if deformation applied physically to IPMCs, it generates an output signal as sensors and energy harvester[2].In this paper, mathematical modeling of taper configuration of IPMC cantilever beam used for energy harvesting from vibration.

2. MATHEMATICAL MODELING

IPMCs is used as energy harvester. Gray box modeling approach is used for modeling of taper cantilever beam as energy harvester. In this study, it is assumed that mechanical and electrical components coupled linearly for modeling purpose only. The transformer circuit usually represents this type of modelling.[3]

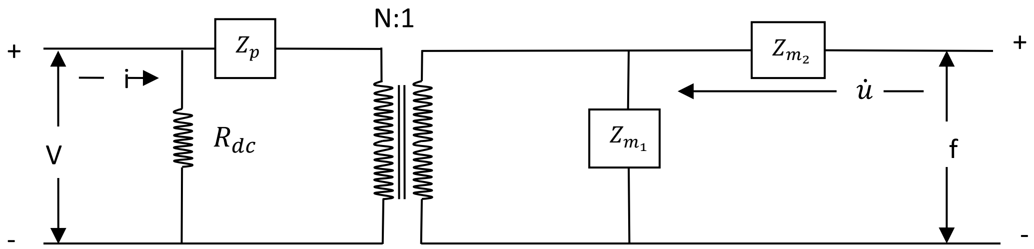

Figure 1 Transformer circuit to represent the electromechanical model of IPMC energy harvester

Quasi-static relationship is assumed for mechanical modeling of Euler-Bernoulli beam, and Mechanical moment *M*, produced due to IPMC bending, as a function of the applied tip force, *f*

$$M = f\left(L_f - x\right) \quad (1)$$

Where, x is the distance from supported end. Bending moment (*M*) can be relates to small deflection (u) as

$$\frac{d^2u}{dx^2} = \frac{M}{YI_Z} \quad (2)$$

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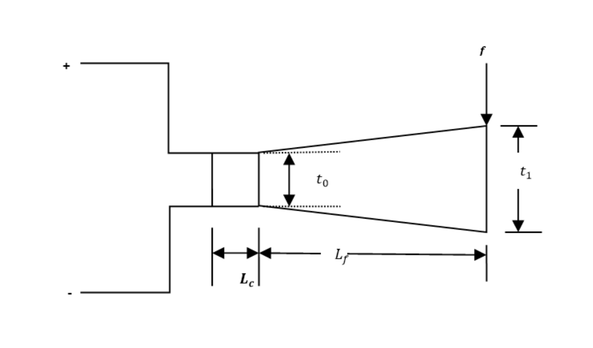

Fig. 2 Mechanical specification of taper IPMC beam

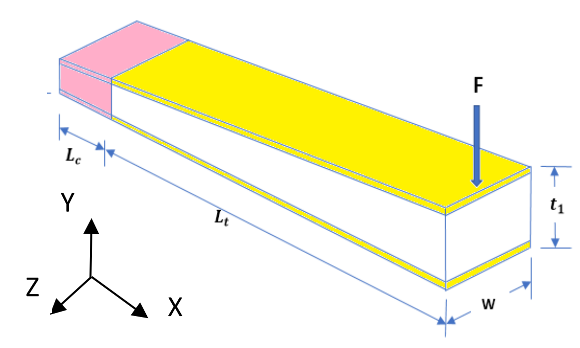

Fig. 3 Taper cantilever beam with parameters

here $$t = t_0 + \left(\frac{t_1 - t_0}{L_t}\right) x$$

After integrating equation (2) twice with respect to x, we get free end deflection as

$$u = \frac{6f}{\alpha^2 wY}\left[\frac{1 + 2\ln t_1}{\alpha} + \frac{(t_1 - 2t_0)L_f}{{t_0}^2} - \frac{(t_1 + 2t_0 \ln t_0)}{\alpha t_0}\right] \qquad (3)$$

Now mechanical impedance (Z_{m_1}) due to stiffness of beam is given by

$$Z_{m_1} = \frac{a^3 wY}{6s[(1 + 2lnt_1) + (p^2 - 3p + 2) - (p + 2lnt_0)]} \qquad (4)$$

Where $\alpha = \frac{t_1 - t_0}{L_f}$ and $p = \frac{t_1}{t_0}$

In addition, mechanical impedance due to inertia of beam given by

$$Z_{m_2} = \frac{\mathrm{a}^3 \mathrm{wA\rho L_f^4 s}}{6(\beta \mathrm{L_f})^4 \mathrm{I}[(1 + 2\mathrm{lnt}_1) + (\mathrm{p}^2 - 3\mathrm{p} + 2) - (\mathrm{p} + 2\mathrm{lnt}_0)]} \qquad (5)$$

Where $\rho =$ density of IPMC and $\beta_1 L_f = 1.875$ for first mode

IPMCs shows resistive behaviour at low and high frequency and capacitive behaviour at intermediate frequency hence IPMC modelled as parallel combination of RC element that are connected in series. Electrical impedance and dc resistance of IPMC is given as

$$Z_p(s) = \frac{1}{2swL_t \sum_{i=1}^{n} \frac{\varepsilon_i}{(1 + s\varepsilon_i \rho_{i)} t_i}} \qquad (6)$$

$$R_{dc} = \frac{\rho_{dc}(t_0 + t_1)}{2w} \qquad (7)$$

here "n" is the degree of freedom required for describing the electrical impedance of IPMC beam and ε_i is the permitivity of IPMC and ρ_i is resistivity of IPMC beam. It assumed that linear electromechanical coupling exhibited by IPMC beam.

$$N = \frac{6d\left[\mathrm{L_f}\left(\frac{1}{\mathrm{t_1}} - \frac{1}{\mathrm{t_o}}\right) + \frac{1}{\alpha}\left(\ln t_1 + \frac{t_o}{t_1} - \ln t_o - 1\right)\right]}{\varepsilon^{\mathrm{T}} \mathrm{w}(\ln \mathrm{t_1} - \ln \mathrm{t_o})} \qquad (8)$$

The equations that represents the equivalent circuit is obtained by applying Kirchhoff's law, we get

$$\begin{Bmatrix} V \\ f \end{Bmatrix} = \begin{bmatrix} \left(\frac{R_{dc}\left(N^2 Z_{m_1} + Z_p\right)}{R_{dc} + N^2 Z_{m_1} + Z_p}\right) & \left(\frac{N R_{dc} Z_{m_1}}{R_{dc} + N^2 Z_{m_1} + Z_p}\right) \\ \left(\frac{N R_{dc} Z_{m_1}}{R_{dc} + N^2 Z_{m_1} + Z_p}\right) & \left(\frac{\left(Z_{m_1} + Z_{m_2}\right)\left(R_{dc} + Z_p\right) + N^2 Z_{m_1} Z_{m_2}}{R_{dc} + N^2 Z_{m_1} + Z_p}\right) \end{bmatrix} \begin{Bmatrix} i \\ \dot{u} \end{Bmatrix} \quad (8)$$

3. RESULTS AND IMPORTANT POINTS

For harvesting vibrational energy from taper cantilever IPMC beam, a sinusoidal force input at the tip of the beam is provided and observing for short circuit current and open circuit voltage. Details of mathematical modeling and numerical results pertaining to the IPMC energy harvester will be provide in the final paper.

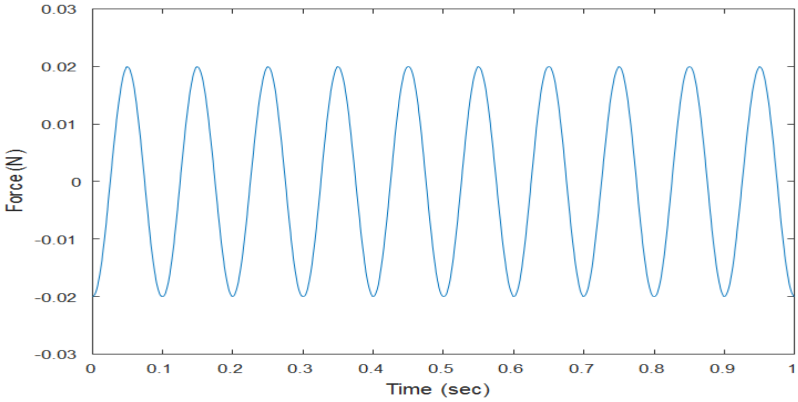

Figure 3 Amplitude and frequency of applied tip force

4. REFERENCES

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