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Dynamic control of porous FGM beam with non variable section via flexible piezoelectric transducers

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Abstract

Materials were originally divided into structural materials, used primarily for their mechanical properties, and functional materials, used for their ability to conduct electrical current, for instance. With smart materials, the functions are embedded in the form and material. Materials become adaptive and evolve. Functionally Graded Materials (FGMs) are a new class of metallic materials.

This work deals with the dynamic control of a porous FGM beam with non-uniform section, using piezoelectric materials. The motion equations are derived based on the Euler-Bernoulli's beam theory and the finite element method through Hamilton's principle. The simulation's results are presented to visualize the states of their dynamics.

Methodology

In our study, we consider the console FGM beam of length L, variable width $b(x)$ and thickness h, composed of a finite number of elements. The upper surface is made of pure ceramic and the lower surface is pure metal. In the upper and lower surface four layers of piezoelectric material are symmetrically bonded, functioning as a sensor/actuator. The width variation is presented by [2] as follows:

$$b(x) = b_0\left(1 - C_b\frac{x}{L}\right)^m$$

The power law is considered to describe the material's properties variation with porosities, from pure metal $\mathrm{z} = -\mathrm{h}/2$ to pure ceramic $\mathrm{z} = +\mathrm{h}/2$:

$$V_c = \left(\frac{2z+h}{2h}\right)^k = 1 - V_m$$

$$E(z) = E_m + (E_c - E_m)\left(\frac{2z+h}{2h}\right)^k - \frac{n}{2}(E_c + E_m)$$

$$\rho(z) = \rho_m + (\rho_c - \rho_m)\left(\frac{2z+h}{2h}\right)^k - \frac{n}{2}(\rho_c + \rho_m)$$

Context

FGMs offer the advantage of continuous variation in mechanical properties. Common to most structures is the problem of vibration, which must be addressed because it can degrade the performance of the structure, cause damage to mechanical components such as structural failure, or lead to premature wear of parts. Even low levels of vibration can cause problems. To answer such a problem, one of the solutions considered consists in active vibration control, which is a powerful technique for reducing or eliminating the transmission of vibration energy in mechanical structures. In the case of thin structures, we often use piezoelectric transducers bonded to the structure. These patches can be used as deformation sensors or as distributed actuators. Such a structure is called "intelligent" because it can obey a control law allowing to dampen vibrations [1].

Results

This work presents a study on the active vibration control of a non-variable section FGM beam. The effects of porosity of the FGM material, as well as the variation of the taper ratio, are taken into account.

Table 1: Variation of vibration frequencies as a function of power index k, porosity index n, taper ratio C_b, for the case of m=1.

k	n	0			0.1			0.2		
	b	2	2.4	2.8	2	2.4	2.8	2	2.4	2.8
0.5		81,9	82,4	82,8	83	83,5	83,9	84,3	84,8	85,3
1		79,6	80,1	80,5	80,5	81	81,4	81,7	82,2	82,6
2		75	75,5	75,9	75,5	76,1	76,4	76,2	76,7	77,2
5		65,5	66	66,3	64,9	65,4	65,8	64,2	64,7	65,1
10		57,6	58,1	58,4	56	56,3	56,7	55,9	56,2	56,5

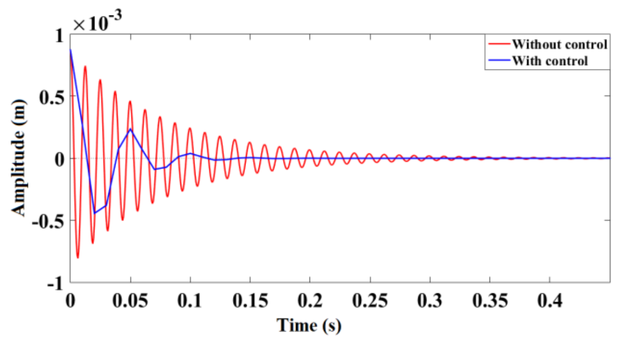

Figure 1: impulse response of the power law, $(\boldsymbol{b = 2};\ \boldsymbol{k = 1}; \boldsymbol{n = 0}; \boldsymbol{m = 1})$

Conclusion and perspectives

From table1 we can see that the increase of the power index k implies a decrease of the vibration frequencies. Then by increasing the power index k the beam contains more and more metal, which leads to a decrease in modulus of rigidity. The decrease of the taper ratio (increase of the width), implies an increase of the material which increases the modulus of rigidity, the thing which explains the increase of the frequencies of vibration. The increase of the porosity index implies increases of the vibration frequencies for $k \leq 2$, on the other hand for values of $k > 2$, the increase of n implies decreases of the vibration frequencies.

The comparison of the controlled and uncontrolled responses shows the success and efficiency of our control procedure.

References

[1] El Harti, K. et al., (2022). Active Vibration Control of Timoshenko Sigmoid Functionally Graded Porous Composite Beam with Distributed Piezoelectric Sensor/Actuator in a Thermal Environment. *Designs*, *7*(1), 2.

[2] Ebrahimi, F., & Hashemi, M. (2017). Vibration analysis of non-uniform imperfect functionally graded beams with porosities in thermal environment. Journal of Mechanics, 33(6), 739-757.