SENSITIVITY ANALYSIS AND CONTROL OF A CANTILEVER BEAM BY MEANS OF A SHUNTED PIEZOELECTRIC PATCH

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ABSTRACT

In this paper, a sensitivity analysis of a beam controlled with a shunted piezoelectric patch is presented. A negative capacitance controller is implemented and a study of stability and performance is performed. Besides, the effects of the technological aspects such as the variability in the material properties or in the position of the piezoelectric patch is evaluated through a finite element simulation.

1 INTRODUCTION

During the last thirty years, vibration control using piezoelectric materials such as lead zirconate titanate (PZT) or polyvinylidene fluoride (PVDF) has been proven to be efficient. Indeed, these materials produce a voltage when strained and conversly strain when exposed to a voltage. Therefore, the mechanical energy can be converted into electrical energy and can be dissipated through a circuit [1]. This technique is called shunted piezoelectric damping. Researches have been led concerning passive shunt [2] or active shunt [3]. The most recent works have shown the efficiency of distributed piezoelectric tranducers [4].

Although, the robustness of such systems, especially the sensitivity of the performances to variations in the material properties in the position of the tranducers, has not been studied. Moreover, the implementation constraints and the nonlinearities of the electronic shunt have not been taken into account during the modelization of the mechanical system. This paper aims at studying the effects of technological aspects such as variability in the material properties or in the position of the piezoelectric patch.

2 SENSITIVITY ANALYSIS

2.1 The mechanical problem

If the design of shunt damping technics has been extensively studied [5–7], the behaviour of the controlled systems in presence of model variations is still unknown. The objective of the sensitivity analysis is to identify which parameter is the more critical when it comes to insure the robustness of the system. We will present here a sensitivity analysis of a 3D cantilever beam controlled by a shunted piezoelectric transducer fixed on one of the surface (see figure 1(a)). The uncertainties considered are :

- the Young modulus of the beam material
- the position of the piezoelectric tranducer
- the thickness of the glue layer

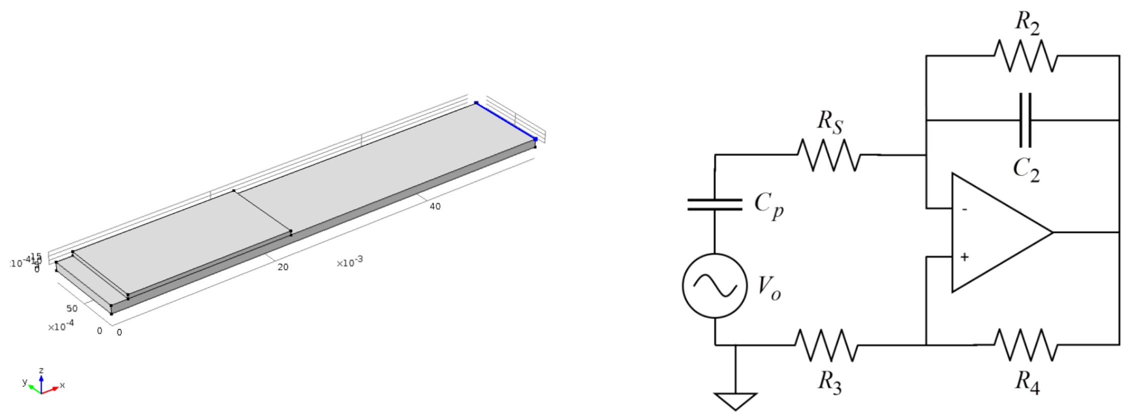
To do so, a multiphysics finite element simulation piloted by a matlab program is performed. Thus, specific functions are built where the entries are the parameters mentioned before and the outputs are the eigenfrequencies and the frequency response. The beam is fixed at one of its end and excited by an harmonic force applied on the other. It is in steel, 1 mm long, 10 mm wide and 5 mm thick. A piezoelctric transducer in PZT-5A is attached on the upper face of the beam, 20 mm long, 10 mm wide and 0.5 mm thick, according to [8].

The tranducer is shunted by a negative capacitance C in serial with a resistor R. With u the voltage between the two faces of the piezoelectric patch, the electric charge applied q applied at a pulsation ω is then :

$$q = \frac{uC}{1 + jRC\omega}$$

2.2 Control sensibility

The choice of C and R has been optimized according to [8] to damp the first bending mode of the beam. By shunting the transducer with a negative capacitance controller, a displacement attenuation of 20 dB is achieved (see figure 2). The damping performances of the first bending mode are found to be robust to a 10% variation of the Young modulus and a 1 mm shift in the position of the tranducer. The induced loss in attenuation does not exceed one decibel *i.e.* 5 %



(a) Geometry of the beam (b) Shunt circuit

Figure 1. Analog implementation of the negative capacitance controller

of the nominal attenuation. Recent works have been led using a negative capacitance controller. For now the implementation is fully analogic, as proposed in [9]. The electric scheme is given on figure 1(b). Although, the stability of the circuit is hard to insure. Moreover, the damping performances are very sensitive to the variations of the negative capacitance. Indeed, as shown on figure 3, a variation of 10% of the capacitance leads to a 2dB loss in damping.Experimentally, a potentiometer is used for the tuning. This operation is manual and has to be performed for every circuit.

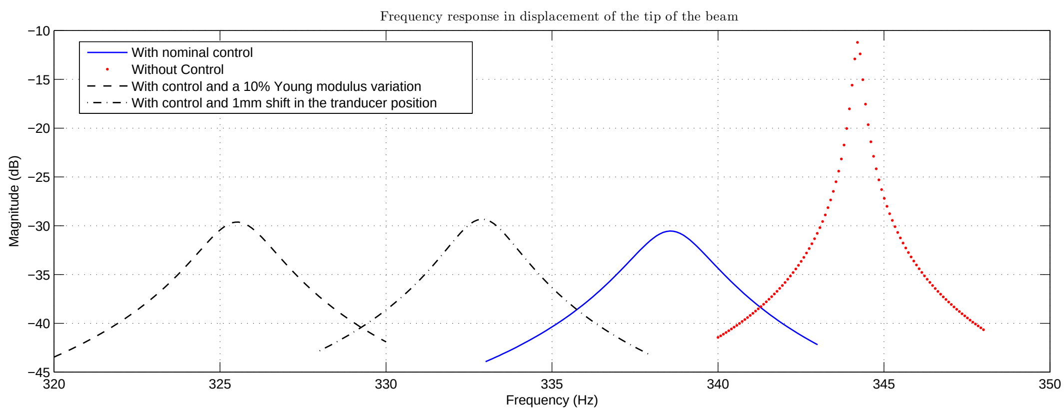


Figure 2. Frequency response in displacement of the tip of the beam

3 CONCLUSION

The performances of the negative capacitance controller appears to be quite robust to a variation of the system properties. Indeed, when controling the first bending mode of the beam, large variation in the material properties and in the position of the tranducer induce a loss of damping of at most one decibel. The electronic circuit has been designed to implement a negative capacitance impedance. However, the damping efficiency relies on a fine tuning of the capacitance. In addition, it is possible to synthetize any king of circuit or filter. By knowing the influence

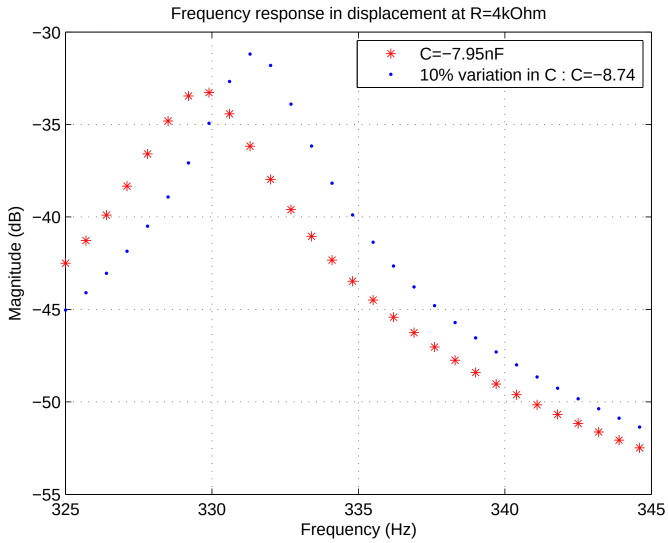


Figure 3. Effects of a capacitance variation

of the technological aspects and the uncertainties on the system performances, an adaptative controller could be implemented to optimize the damping performances in real time.

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