MAGNETICALLY INDUCED VIBRATIONS ON A CONDUCTIVE CANTILEVER FOR RESONANT MICROSENSORS

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Abstract : A conductive and non-magnetic cantilever, located in a time-changing magnetic field, is brought into resonance thanks to the interaction between the eddy currents and the external magnetic field. In order to exploit this effect for resonant sensors, an experimental set-up has been built and a simple theoretical analysis has been used to model the relevant features of the sensor by means of electro-magnetic-mechanical device simulations. Experimental results demonstrating the principle are reported.

Keywords: resonant sensors, magnetic activation, autonomous sensors.

INTRODUCTION

In some specific applications, the measuring environment has characteristics unsuitable for the correct working of the electronics, because it is not possible to connect the sensitive element to the conditioning electronics by standard cables and an autonomous source of power is not available. A possible solution can be a contact-less activation of a passive sensor through a magnetic field.
Sensors, also obtained from MEMS technology [1,2], based on change of resonance are sensible to different type of physical and chemical quantities. The technique proposed here can be applied to resonant micro-sensors obtained through a MEMS technology based, for example, on a standard CMOS process coupled with only non magnetic layers [3].

OPERATING PRINCIPLE

As shown in fig. 1, a conductive cantilever (whose left side face is in the z=0 plane) is located in a static and in a time-changing magnetic flux field [4,5]: the time changing field B_0 has both transverse (B_{0z}) and in plane (B_{0p}) components. Moreover the static one (B_1) has both transverse (B_{1z}) and in plane (B_{1p}) components. The transverse time-changing magnetic field generates eddy currents in the cantilever; the external dynamic and static magnetic flux fields (B_0 and B_1) and the induced currents in the cantilever are then responsible for electromagnetic forces acting on the cantilever. We first want to characterize these forces in order to exploit their possible use in a resonant sensor.
Neglecting displacement currents, the relation between transverse magnetic fields (H_z) and in plane eddy currents and electric fields (E_p) is governed by Maxwell equations:

$$\nabla \times E_p = -\frac{\partial B_z}{\partial t} = -\left(\frac{\partial B_{0z}}{\partial t} + \frac{\partial B_{ez}}{\partial t} \right) \quad (1)$$

$$\nabla \times H_z = J_{ep} = \sigma E_p \quad (2)$$

$$B_z = \mu_0 H_z = \mu_0 \left(H_{0z} + H_{ez} \right) \quad (3)$$

where B_{ez} is the (transverse) magnetic flux induced by the (in plane) eddy currents (whose density is (J_{ep}) and σ is the electric conductivity of the beam. Applying the curl operator to equation (2), in the limit of very small conductive sheet thickness (h), we get the following equation for the magnetic field induced by the eddy currents:

$$\nabla^2 H_{ez} - \mu_0 \sigma \frac{\partial H_{ez}}{\partial t} = \sigma \frac{\partial B_{0z}}{\partial t} \quad (4)$$

Solving equation (4) we then get the eddy currents distribution by eq. (2) and the electromagnetic force from Lorentz equation:

$$F = h\, J_{ep} \times \left(B_0 + B_1 + B_{ez} \right) \quad (5)$$

Note that, due to the mechanical constraint (the dark region of the cantilever in Fig. 1), transverse magnetic flux field components are responsible for compression of the beam, while in plane components exert a torque. The static flux field in relation with the J_{ep} produces

a force at the same frequency of J_{ep}, while the time changing magnetic flux field and the J_{ep} produce a force at double frequency.
Once the electromagnetic forces have been determined, the electromagnetic problem is coupled to the mechanical one to obtain the dynamic evolution of the cantilever displacement.

EXPERIMENTAL SYSTEM

A system consisting of a piezoelectric bimorph cantilever, used as a transducer, and a coil inductor, used as a magnetic field generator, has been made to verify the possibility to induce vibration. Two aluminum sheets (thickness 20μm) have been glued on the two sides of the bimorph (Fig. 1). Aluminum has a conductivity (σ) of $37.7 \cdot 10^{6} (m \cdot \Omega)^{-1}$ and it is a non-magnetic material. A charge amplifier measures the vibrations induced into the piezoelectric cantilever and a power amplifier drives the coil. The input signal to power amplifier is sinusoidal at f frequency and it is supplied by function generator (HP3325A). Moreover the inductance core presents a static flux field B_1 that has been measured by a magneto-resistive sensor. From equation (5) we expect that, driving the coil with a sinusoidal current at f frequency, the forces on the cantilever have at least two sinusoidal components: one at f and the second at $2f$.

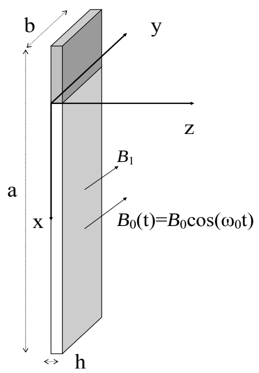


Fig. 1. Schematic drawing of the conductive cantilever (15x1.5x0.6mm)in a time-changing magnetic field.

The geometry is reported in figure 2: the bimorph is clamped to a fixed support and the conductive part is put into the air gap of the inductor core.

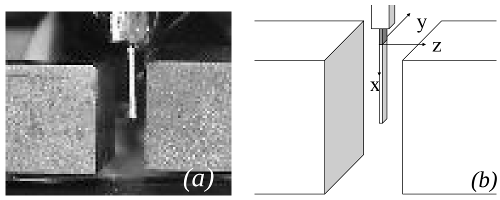


Fig. 2. A picture of the experimental set-up (a) and its schematic drawings (b).

EXPERIMENTAL RESULTS

In order to modify the mechanical resonance of the cantilever, two drops of different quantities of plastic polymer have been deposited on the cantilever. The experiments have been conducted on the cantilever charged with three different mass quantities that, in the followings, are called: 1) no drop; 2) one drop and 3) two drops.
The impedance of the cantilever has been measured by an impedance analyzer (HP4194A), and three different diagrams corresponding to the previous defined three cases are shown in figure 3.

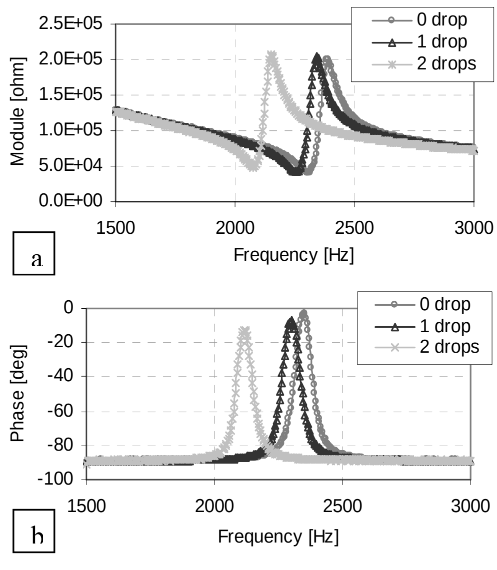


Fig. 3. The impedance modules (a) and their phases (b) of the cantilever.

From the experimental data, the mechanical resonances has been calculated as the frequency f_m where the real part of the admittance has its maximum and the three values obtained are reported in the first column of table 1.

Tab. 1. Mechanical cantilever resonances and the input signal frequencies used.

Drops	f_m	$\sim\frac{1}{2} f_m$
0	2320 Hz	1160 Hz
1	2268 Hz	1130 Hz
2	2090 Hz	1045 Hz

As reported previously, if the current driving the coil is a sinusoid at f frequency, the force has at least f and $2f$ components. The coil has been driven at f frequency and a spectrum analyzer (HP4194A) measures the spectrum of the charge amplifier output. Moreover also the spectrum of the current driving the coil has been measured to exclude the presence of harmonics greater than the fundamental.
The f frequency of the current driving the coil has been set to $\frac{1}{2}f_m$. When no mass is charged over the cantilever ("no drop" case) the input and output spectrum diagrams are reported in figure 4.

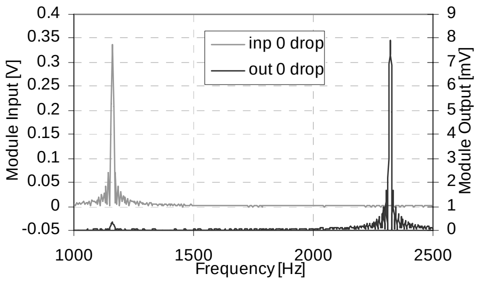


Fig. 4. The input and output spectrum diagrams calculated at zero mass charge with the input signal frequency of ½ f_m.

While the input clearly has only its fundamental, the output spectrum shows two peaks: the first placed at f frequency and the second with a very high module because corresponds to f_m. When the polymer drops are deposited onto the cantilever ("one drop" and "two drops" cases), a similar behavior has been observed. Figure 5 shows the output spectrums in a short frequency range, for the three cases, each driven at its $\frac{1}{2}f_m$ as reported in the second column of table 1. As it can be seen the resonance frequency value and its magnitude decrease with the increase of the mass on the cantilever.

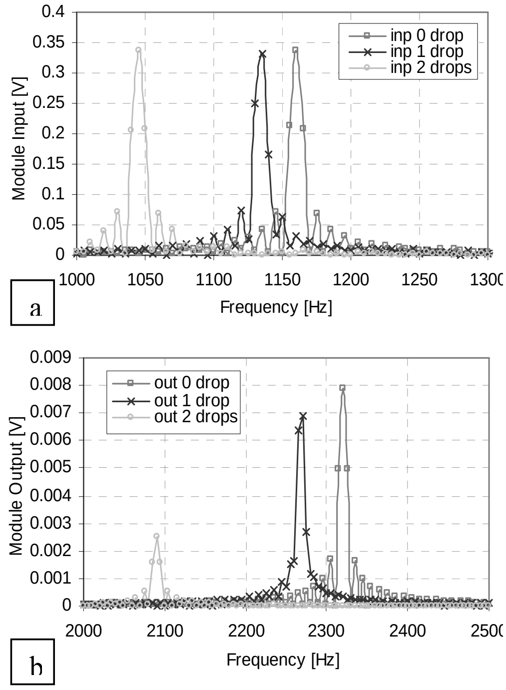


Fig. 5. The ½ f_m input (a) and their output (b) spectrum diagrams of the signals at different mass charges.

In figure 6 the sinusoidal input signal has a frequency (350Hz) that is not a multiple of the mechanical resonance frequency. The output diagram shows a peaks at 350Hz and another at double frequency 700Hz, both have lower values.

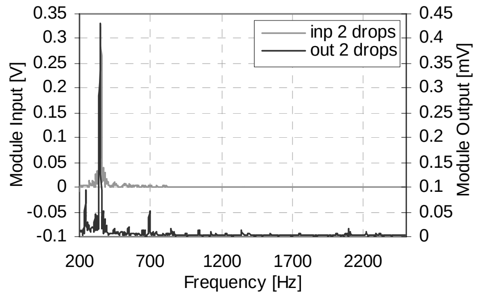
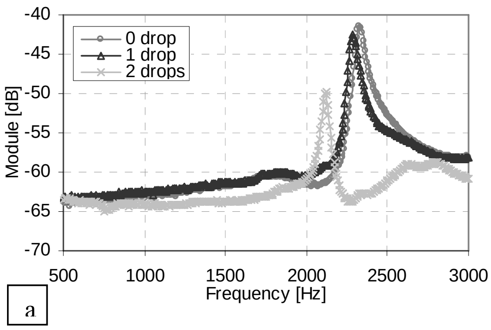


Fig. 6. The input and its output spectrum diagram of the signal at non-multiplied frequency.

An alternative method to measure the resonance and its changes due to different applied masses is to obtain the frequency response of the system.

A network analyzer (HP4194A) has been used to measure the module and phase of the frequency response of the experimental system, by driving the power amplifier and measuring the charge amplifier output.

Figure 7 shows the experimental data and again the diagrams when the cantilever is charged with plastic material on its tip. The modules have resonances lower than the corresponding resonance of the unloaded cantilever. The frequency response is also affected by cross talk problems, probably due to electromagnetic interference.



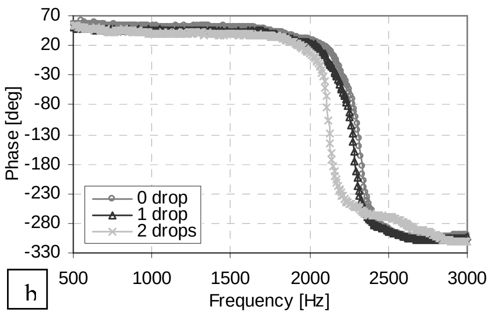


Fig. 7. The module (a) and phase (b) diagrams of the signals at different mass quantities.

CONCLUSIONS

In this paper the possibility to induce vibrations and resonance on a conductive and non-magnetic cantilever by a transverse variable magnetic field has been discussed and has been experimentally demonstrated. The change of mechanical resonance induced by applying different masses on cantilever has been measured. The force acting on the cantilever arises, as also confirmed by the mathematical results, from the interaction between the eddy current, induced in the conductive cantilever by the variable magnetic field, and the same magnetic field. The proposed technique can be used for development of resonant microsensors in MEMS technology based on a standard CMOS process coupled with only non magnetic layers.

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