# Analysis and characterization of Magnetostrictive Vibrators

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Magnetostrictive vibrators employ the magnetostriction properties of ferromagnetic material to trigger the structural resonance of the magnetic core. Hence, they are found in energy harvesters, mini-actuators and ultrasonic instruments. In this abstract, we present the analysis and the experimental characterization of a U-shape magnetostrictive vibrator.

*Keywords: Magnetostriction, Mechanical resonance, Vibration*

## 1. Introduction

Magnetostrictive vibrators are composed of a ferromagnetic part with large magnetostriction excited by an alternating magnetic field through a coil. Magnetostrictive vibrators have various application such as mini-actuators [1-2], energy harvesters [3], and ultrasonic instruments [4]. In this abstract, we present the analysis and the characterization of a magnetostrictive vibrator equipped with a permanent magnet.

## 2. Results and discussion

The magnetostrictive vibrator under investigation is composed of a NiZn ferrite core. It operates at 20 kHz with a biased DC flux produced by a permanent magnet. The dimensions and main properties are reported in [4]. The experimental characterization of the device aims at predicting the vibration level under different current level to ensure the required vibration for the ultrasonic application. In Figure 1, the magnetostrictive vibrator is equipped with strain gauge sensors, two search coils to measure the magnetic field, *h,* and the flux density, *b*. The operating principle of the magnetostrictive vibrator is validated by measuring the strain under different frequency. The resonance peak is measured at 16 kHz and high level of vibration remains beyond. The magnetic properties are evaluated by conducting measurements with and without permanent magnets. The parameters $a$ and $j_s$ of a Langevin's function and the remanence $j_r$ of the permanent magnets are fitted to match the magnetic measurements. $b = \mu_0\, h + j_s\left(\coth\left[\frac{h}{a}\right] - \frac{a}{h}\right)$ with the vacuum permeability $\mu_0$. In Figure 1, the magnetic properties are represented with the fitted magnetic model. The comparison with the measurement validates the selected model of the anhysteretic $bh$ curve.

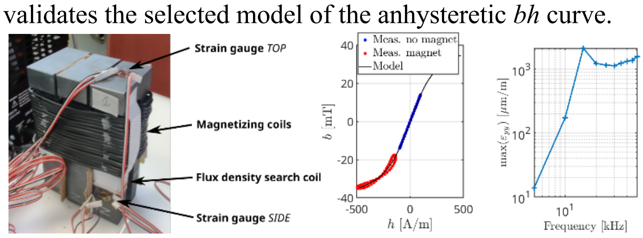


Figure 1: Vibrators with sensors in the left. Magnetic properties at 20 kHz, in the middle. Impact of the frequency on the strain peak, in the right

The distribution of the magnetic flux density is computed by solving a 2D magnetostatic problem over the vibrator surface $S$, in FreeFem++. The magnetostatic formulation is solved with the magnetic vector potential $a_z$.

$$\int_S h(b)\nabla a_z \mathrm{d}s = \int_S J_z\, a_z \mathrm{d}s + \int_S \frac{j_r}{\mu_0}\nabla a_z \mathrm{d}s \qquad (1)$$

In practice, the current density, $J_z$, flowing in the winding is adjusted to fit with the measured magnetic field. The non-linear problem is solved with a Newton-Raphson iterative scheme. The magnetostriction $\lambda$ is modelled with a polynomial expression of $j/j_s$, where $j$ is magnetic polarization.

$$\lambda(j) = \lambda_s\left[a_\lambda\left(\frac{j}{j_s}\right)^2 + c_\lambda\left(\frac{j}{j_s}\right)^6 + e_\lambda\left(\frac{j}{j_s}\right)^{10} + g_\lambda\left(\frac{j}{j_s}\right)^{14}\right] \qquad (2)$$

The polynomial coefficients $a_\lambda$, $c_\lambda$, $e_\lambda$, and $g_\lambda$ are identified from the magnetostriction of alloys with similar symmetry. The magnetostrictive strain tensor $\boldsymbol{\varepsilon}_\mu$ is assumed diagonal and its components are expressed with the direction of the polarization direction $\boldsymbol{e}$ by $\boldsymbol{\varepsilon}_{\mu_{ii}} = \lambda(j)[e_i{}^2 - 1/3]$. The time-harmonic mechanical problem is solved in 3D over the vibrator volume $V$ by extruding the 2D geometry. The problem is formulated at the pulsation $\omega$ with the displacement $\boldsymbol{u}$, the test function $\boldsymbol{v}$, the mass density $\rho$, and the Lamé parameters $\mu_e$, and $\lambda_e$.

$$\int_V -\rho\omega^2\boldsymbol{u}\cdot\boldsymbol{v} + \lambda_e(\nabla\cdot\boldsymbol{u})\cdot(\nabla\cdot\boldsymbol{v}) + 2\mu_e\boldsymbol{\varepsilon}(\boldsymbol{u}):\boldsymbol{\varepsilon}(\boldsymbol{v})\mathrm{d}\xi = \int_V 2\mu_e\boldsymbol{\varepsilon}_\mu:\boldsymbol{\varepsilon}(\boldsymbol{v})\mathrm{d}\xi\,, \qquad (3)$$

the strain is $\boldsymbol{\varepsilon}(\boldsymbol{u}) = (\nabla\boldsymbol{u} + [\nabla\boldsymbol{u}]^T)/2$. The magnetostriction constant $\lambda_s$ is identified to match with the peak of the measured strain. The Figure 2 presents the results of the model with the fitted parameter. The model validation will be presented in the full paper.

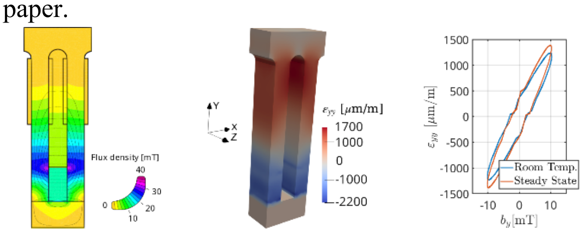


Figure 2: In the left, 2D magnetic model of the magnetostrictive vibrator with its supportive foam. In the middle, 3D mechanical model of the vibrator at 20 kHz. In the right, measured $y$-component of strain from the sensor placed on the side.

## References

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