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Design, Simulation, Construction and Characterization of a Vibrant Magnetic Structure for its Use in Magnetostrictive Energy Harvesters

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Introduction

Most industrial processes often generate vibrations at relatively low frequencies, around 100 Hz [1]. These vibrations can be harnessed to generate green electrical energy through vibration harvesters, being piezoelectric ones the most commonly used. However, at this frequency interval these devices display the disadvantage of requiring a larger size as the vibration frequency reduces. This study aims to design and optimize, based upon mechanical criteria, a U-shaped vibrant magnetic structure to be employed as the core of a magnetostrictive harvester, offering an alternative to substitute piezoelectric ones in low-frequency industrial applications.

The importance of the analysis relies on the fact that the performance of the harvester highly depends on the mechanical properties of the vibrant structure and on the design parameters, fundamentally: the resonance frequency, the stresses, and the displacement amplitudes under vibration. Their enhancement enables the design of a low resonance frequency, compact, long-lasting and cheap device whose features will permit the massive application to industrial processes and even at remote locations.

Harvester Design and Simulation

In a magnetostrictive vibration energy harvester electrical energy is obtained as indicated in Figure 1, thanks to an active magnetostrictive material through Villari effect (Galfenol was used in the case of this work due to its proper balance between cost and performance).

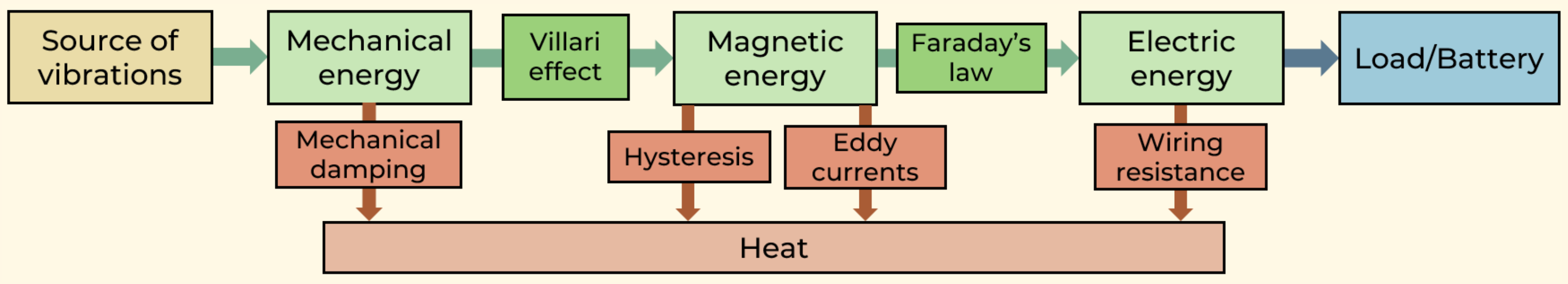


Figure 1. Energy flow diagram of a magnetostrictive vibration energy harvester.

Villari effect consists on a change on the material magnetization $\boldsymbol{M}$ (for a given external field $\boldsymbol{H}$) when the sample is subjected to mechanical stresses, $\boldsymbol{\sigma}$, as illustrated in Figure 2.

Among the different configurations, the bending-type U-shaped harvester proposed by Ueno in [2] was chosen for its low cost and high performance. An scheme of this configuration is shown in Figure 3.

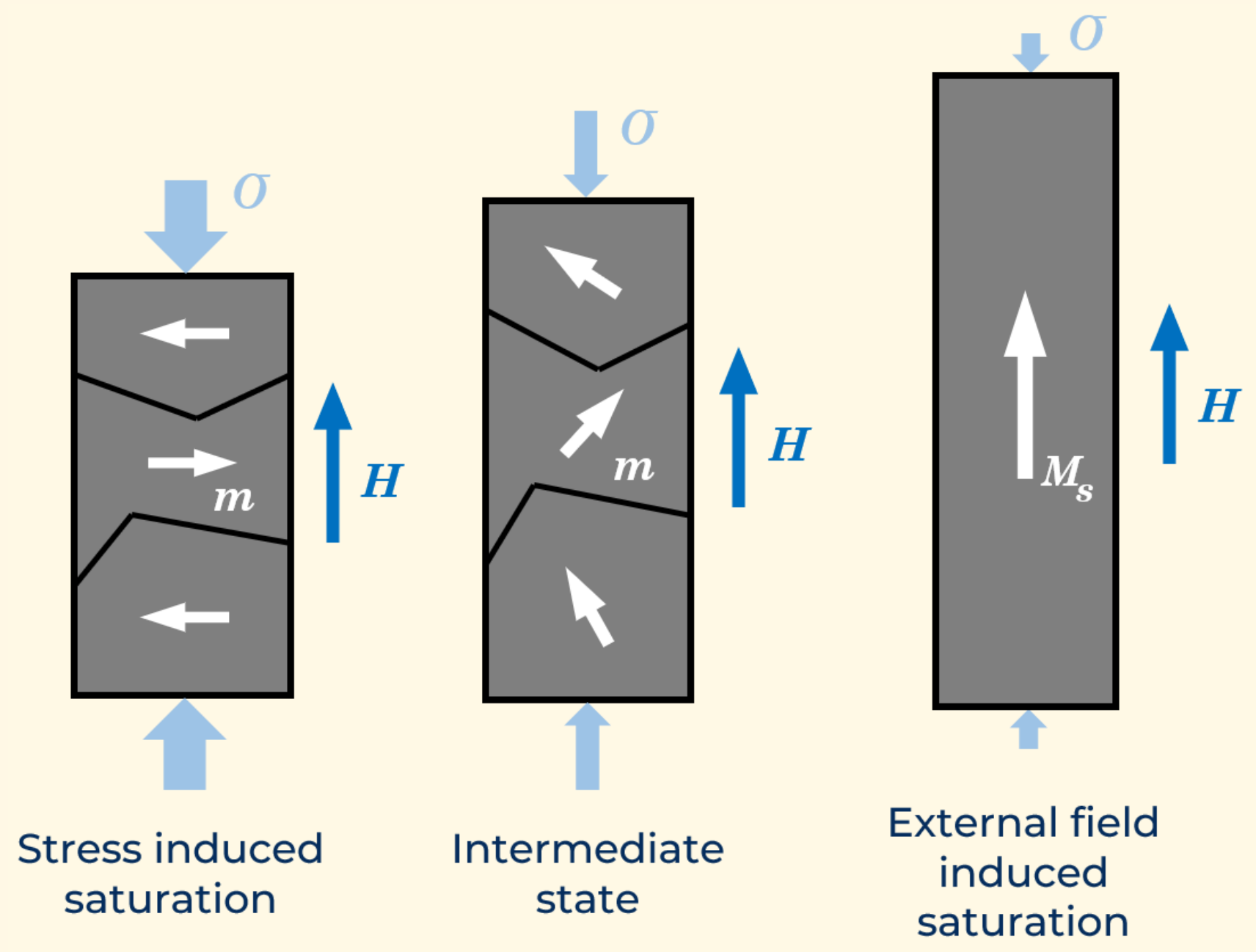


Figure 2. Villari effect as applied stress is decreased.

The designed structure is built from a 0.5 mm thickness gray cast iron plate with dimensions 4 × 88.4 mm, bent in such a way that the length of the device is 5 cm. These dimensions where obtained from an iterative static and dynamic simulation process in MATLAB® to obtain the first frequency mode at around 100 Hz, while maximizing the stresses where the 20 × 4 × 0.5 mm as-cast Galfenol sheet is located.

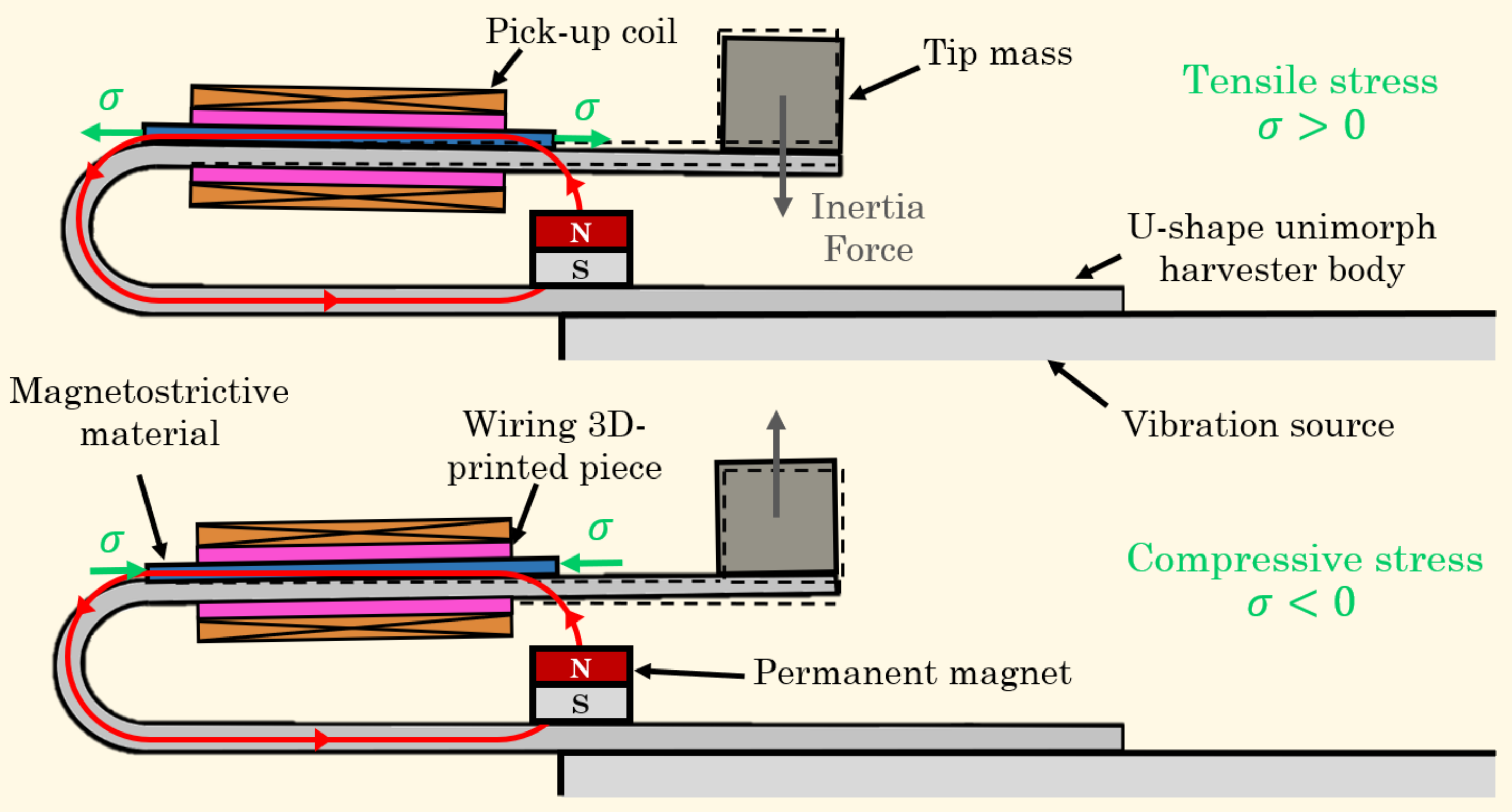
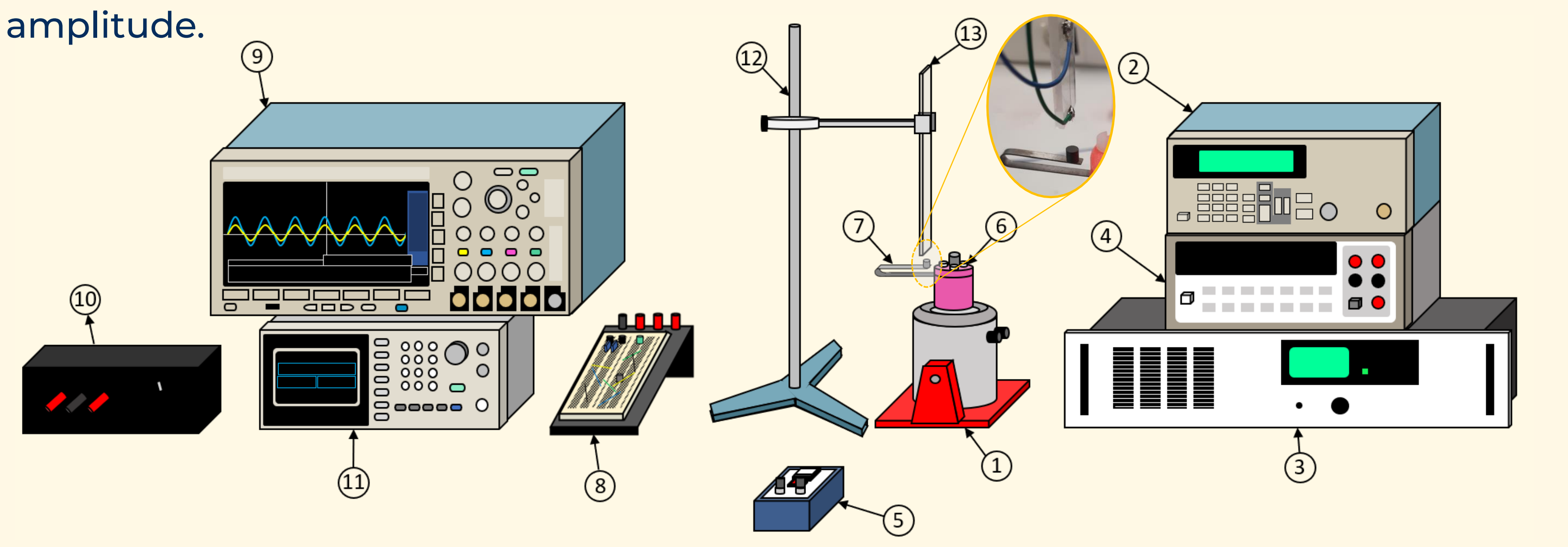


Figure 3. U-shaped harvester configuration proposed by Ueno in [2].

Magnetic Structure Characterization

The magnetic structure prototype was characterized in the laboratory using the setup in Figure 4 to compare empirical results with the simulation ones. The setup elements from 1 to 7 were used to generate the ambient vibrations and the rest to characterize the structure vibration by using a Giant Magnetoimpedance Effect (GMI) sensor and a cylindrical ferrite magnet as tip mass. After calibrating the GMI sensor at 10 Hz to ensure that no resonance was present, the resonance frequency ω_0, and amplitude of vibrations X_0, were measured at a constant ambient vibration amplitude.



1. Shaker
2. Function generator
3. AC amplifier
4. Ammeter
5. Accelerometer
6. 3D-printed harvester support
7. Prototype
8. Sensor circuit board
9. Oscilloscope
10. DC circuit board supply
11. AC circuit board supply
12. Support
13. Vibration magnetic sensor

Figure 4. Laboratory setup for prototype characterization.

Results and Discussion

Table 1 shows the results for ω_0 and X_0 for different configurations created by adding future harvester elements to the magnetic structure. It is observed ω_0 can be easily tuned by changing the tip mass. The damping coefficients α and β were chosen in such a way that the error between the theoretical and empirical results was minimized. Figure 6 shows good agreement between both results.

Table 1. Comparison of results for different configurations at 0.1 mm constant shaker amplitude.

Setup	No Galfenol sheet and 3D-printed piece	With Galfenol sheet and 3D-printed piece	With extra 2.1972 g tip mass
ω_0 (Hz)	113	111.5	56
X_0 (mm)	3.48	5.02	0.71

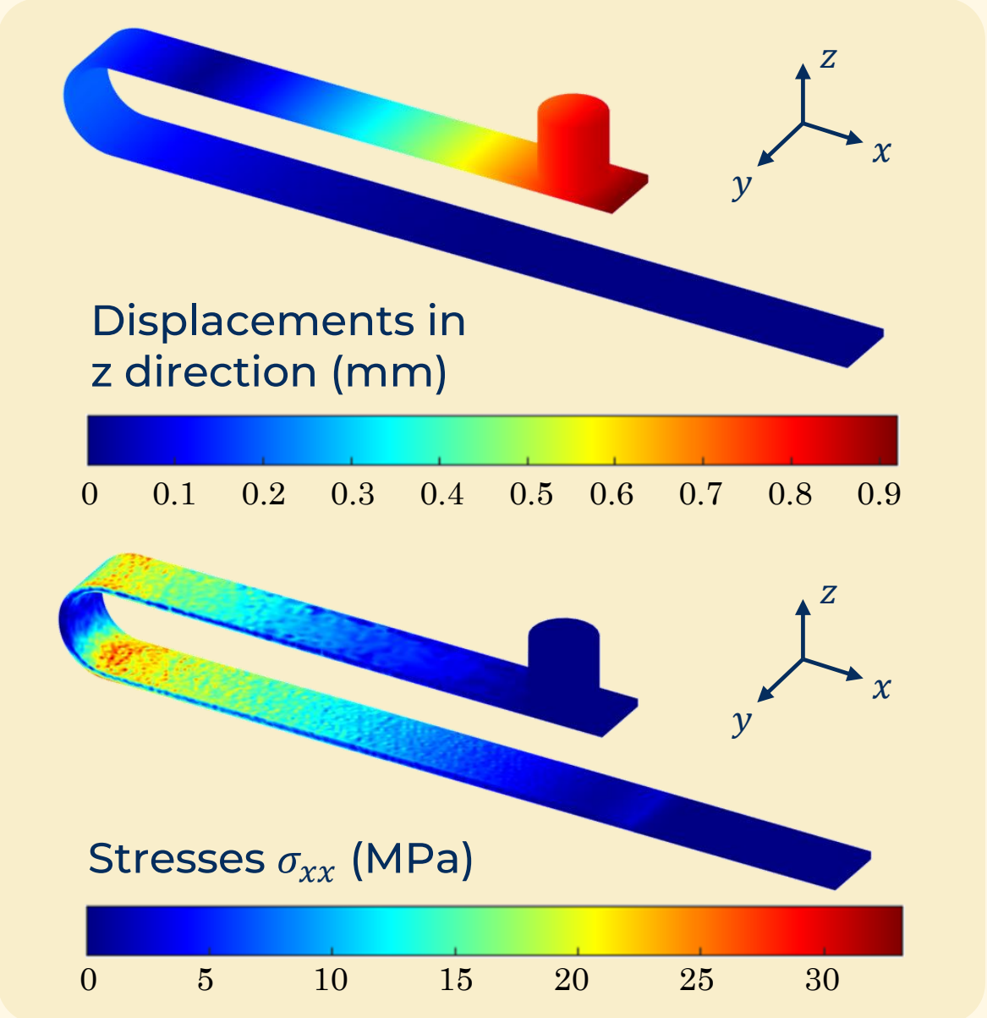


Figure 5. Dynamic simulation results.

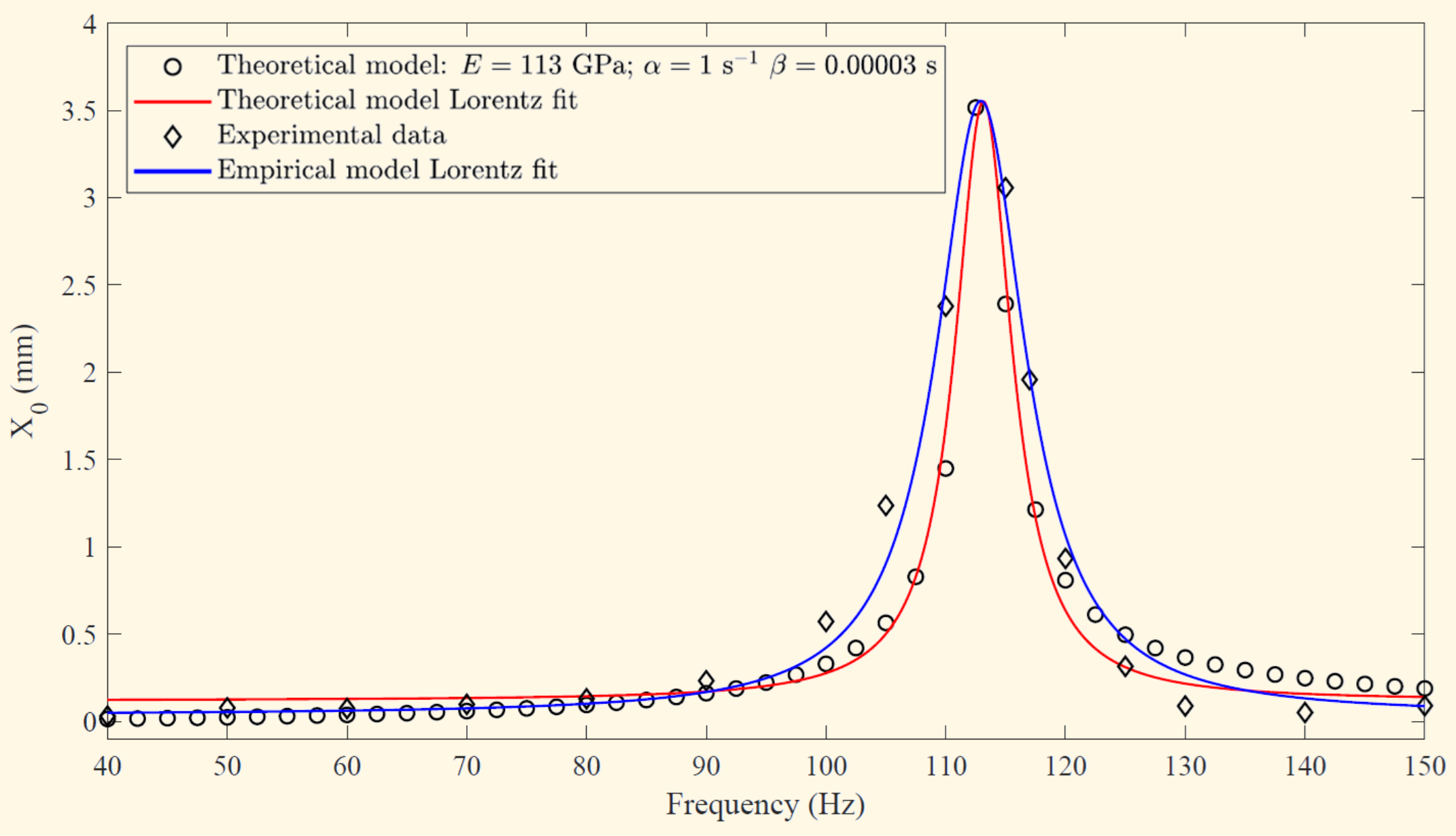


Figure 6. Comparison of theoretical and empirical results.

Conclusions

In conclusion, a low-cost, compact, and durable magnetic vibrant structure was designed from the initial proposal of Ueno in [2]. Through MATLAB® static and dynamic simulations, the design was optimized and validated in terms of resonance frequency, stresses and displacements. Experimental characterization of the prototype confirmed its excellent resonance frequency tuning capabilities, which could enhance the harvester's performance in various applications. Finally, theoretical predictions aligned well with empirical data, providing an accurate estimation model of the harvester's features prior to construction.

References

[1] L. Tang, Y. Yang and C. K. Soh, "Toward Broadband Vibration-based Energy Harvesting," *Journal of Intelligent Material Systems and Structures*, vol. 21, pp. 1867–1897, Dec. 2010.

[2] T. Ueno, "Magnetostrictive low-cost high-performance vibration power generator," *Journal of Physics Conference Series*, vol. 1052, no. 1, p. 012075, Jul. 2018.