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INVESTIGATIONS ON AN ADAPTIVE HELMHOLTZ RESONATOR CONCEPT

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ABSTRACT

Helmholtz resonators have been historically one of the first engineered concepts for acoustic control. They can be used either for increasing sound at a specific frequency, or create antiresonances depending on the way they are implemented. In terms of acoustic control for industrial applications, they constitute very efficient solutions for tonal excitations with a fixed frequency. The resonance frequency of the resonator has to be tuned on this frequency, meaning that if any change occurs in the excitation frequency, the control is no longer possible with the resonator. The concept proposed here to overcome this limitation consists in designing a Helmholtz resonator with a variable volume, that can be controlled in real-time. On the basis of waterbomb origami design, multiphysics simulations are performed to define the geometry of the adaptive cavity. After manufacturing, experimental tests are used to validate the models and illustrate the efficiency of the concept.

1 INTRODUCTION

Helmholtz resonance is the name given to the resonance phenomenon occurring in a cavity linked to the surrounding atmosphere (which is usually air) via a constricted neck or necks. Hermann L. F. von Helmholtz [1] established first its physical and mathematical principles. The most common example for Helmholtz resonators, are bottles and stringed instruments, especially bottles given the fact that they fit the description very well (small opening into a large chamber) [2]. As the frequency is controlled by the geometrical properties of the resonator [3–5], controlling the geometry of the device (such as the volume of the cavity), means controlling the frequency at which noise reduction is desired. Following this line of reasoning, creating an adaptive Helmholtz resonator is a valid option. There are several works in the literature that address the subject of tunable Helmholtz resonators and the most effective means of using them in order to control sound and thereby, achieve noise attenuation. De Dedout [6] proposed an adaptive-passive noise control with self-tuning Helmholtz resonators, where a varying cavity volume was achieved, by adding two rigid walls inside the cylindrical resonator cavity. Both walls were linked to each other at the center of the cavity, allowing easily the rotation of the movable wall through a DC motor. Rigid walls being difficult to use to obtain continuously varying volumes, polymers have been at the center of recent works to try to tune the frequency of acoustic resonators. Yu [7] proposed a tunable acoustic metamaterial with an array of (non-Helmholtz) resonators actuated by a dielectric elastomer. Abbad used a similar material to control an elastic resonance of a membraned Helmholtz resonator [8], but also its volume [9]. Following this strategy, relatively small volume variations can be obtained, hence in this work, a new concept is proposed: in order to obtain large volume variations, an origami-based design is investigated.

2 GEOMETRY OF THE ADAPTIVE HELMHOLTZ RESONATOR

Origami designs offer extreme reconfigurability and a wide range of deployability thanks to their hinges rotation and their facets deformation. This can be exploited to create lightweight devices with controlled characteristics and tunable properties [10]. The origami base chosen here, on the basis of the requirements and state of the art [11, 12] is the waterbomb (see fig. 1). The origami waterbomb base is a single-vertex origami mechanism with unique characteristics that may prove advantageous in a wide range of applications, one of which is vibro-acoustics. The base shows a high potential as a testbed for smart materials and integrated actuation systems thanks to its straightforward geometry and multiple phases of folding/unfolding motion, that ranges from simple (completely flat) to more complex (3D configurations) [13]. The cavity is closed with an end part, which was inspired by the mechanism of the umbrella. This last part keeps the cavity closed during the folding and unfolding of the resonator. On the opposite side, a cylinder is used as resonator neck.

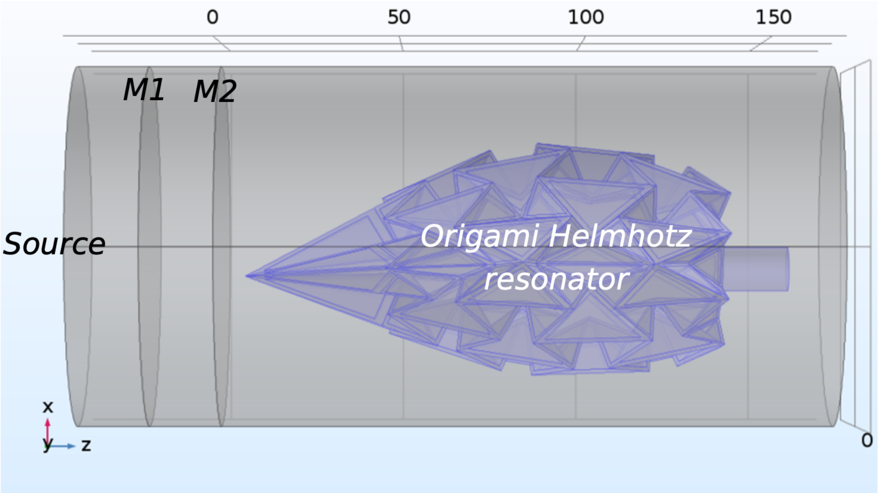

Figure 1: View of the waterbomb Helmholtz resonator in the computation configuration (impedance tube)

3 MULTIPHYSICS SIMULATIONS

In order to define the optimal design of the adaptive Helmholtz resonator, several multiphysics simulations are performed.

- Analytical expressions of resonance frequency are first used to define the macroscopic volume and neck characteristics to achieve the expected frequency shift;
- acoustic finite elements computations are then used by considering rigid walls on the origami structure, in order to check the effect of the complex geometry on the resonance frequency and absorption properties of the resonator (losses in the neck are included in these computations);
- vibro-acoustic coupled finite elements computations are performed to check the effect of walls resonances on the properties of the resonator (structural losses are considered here);
- PTMM [14] computations are used to understand the effect of losses in the constrictions of the origami;
- Nonlinear structural computations using hyperelastic models for the origami walls are finally used to check the foldability and required forces to tune the resonance frequency.

These computations are used to design the final geometry of the Helmholtz resonator, which is manufactured in the lab.

4 EXPERIMENTAL CHARACTERIZATION

Experiments are performed in an impedance tube, using the various folding states of the origami.

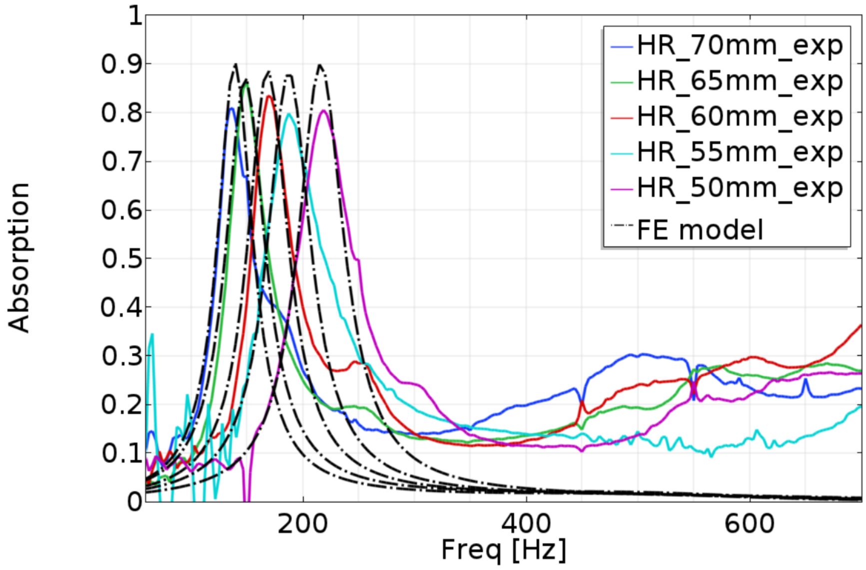

Figure 2. Comparison of experimental tests and simulation results

Results are presented in Figure 2, in terms of absorption coefficient, for several configurations expressed in terms of maximum external diameter of the origami resonator. As expected, the larger the volume, the lower the resonance frequency. A shift from 138 Hz to 219 Hz can be obtained by unfolding the resonator from 50 mm diameter to 70 mm diameter. The resonance frequency and the maximum absorption level are well captured by the model, however the slight increase of absorption coefficient above 400 Hz is not reproduced and may be due to unperfect gluing/manufacturing/geometry of the tested device. The efficiency of prediction of the frequency and levels around the resonance frequency, compared to experimental tests, illustrates the applicability of the adaptive origami-based Helmholtz resonator for practical applications.

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