

Modal Analysis of Multi-Material Resonator Elements for Acoustic Metamaterials

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Abstract

Acoustic metamaterials have introduced highly effective concepts to dampen vibrations with sub-wavelength elements, especially in the low frequency range. With advances in additive manufacturing, it is now possible to manufacture parts that are composed of multiple materials without any need for assembly. In this study, a previously investigated resonator design is extended with a visco-elastic insert in the spring section of the resonator element. Multiple variants with different insert geometries are designed and manufactured using MultiJet Modeling with two different photo-polymers. A variant without insert is also manufactured as a baseline for all comparisons. Multiple instances of each design are measured, utilizing a 3D-Laser-Scanning-Vibrometer. In a previous study [1], the general suitability of the rigid photopolymer is assessed and compared to resonators made from ABSplus and PLA with Fused Filament Fabrication. In this study, the multi-material variants are analyzed regarding their modal behavior.

Introduction

“Metamaterials are artificially produced materials with properties that are different from the properties usually observed in naturally occurring materials [2]. The term was originally introduced in the field of electromagnetic wave propagation by Russian physicist Victor Veselago [3], and describes materials that incorporate small periodic structures that result in e.g. negative index of refraction or negative electrical permittivity.

Many of the concepts can be transferred to acoustic wave propagation. Conventional materials such as steel, aluminum or polymers have a well understood dynamic behavior and follow the laws of linear structural dynamics. Acoustic Metamaterials differ from that and display properties like a locally negative dynamic mass or negative dynamic stiffness.

Concepts incorporating small periodic resonator elements have been shown to be extremely efficient in sound absorption, within a narrow frequency band and at a highly sub-wavelength size, e.g. in [4]. Due to the complex geometry of the structures, these concepts usually rely on Additive Manufacturing (AM) processes.” [1]

Resonator design and experimental setup

Recent advances in AM allow for multi-material printed parts, which gives the engineer a new degree of freedom for the design of metamaterials. The printer that was used in this study is a *Stratasys Objet260 Connex*, which utilizes the Polyjet technology. The part is built from liquid resin droplets that are hardened with UV light. The materials that were used are *VeroWhite* (similar to PA) and *Agilus30* (rubber-like).

The specimen design (Figure 1) as well as the experimental setup are based on a previous study by the author [1].

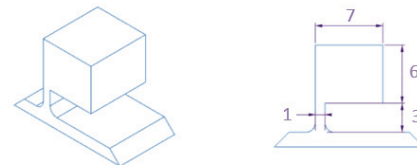


Figure 1: Base geometry for the resonator element (ID1500, comp. Table 1), based on a previous study [1]

In the previous study the variance in the modal behavior was investigated for different materials, additive manufacturing processes and geometries. The parameters for the different geometries are listed in Table 1. The resonators were printed with FDM printers in ABSplus and two different PLA strains, and with a Polyjet printer in VeroWhite. The latter resonators are also used as reference in this publication.

Table 1: Geometry parameters for the resonator variants

Element ID	Depth [mm]	Width [mm]	Height [mm]	Arm [mm]
1000	8	7	4	2
1100	8	7	5	2
1200	8	7	6	2
1300	8	7	4	3
1400	8	7	5	3
1500	8	7	6	3

In the present study the approach was extended with a two-material version of the resonator, as displayed in Figure 2. A 1 mm layer of the rubber-like material was added to the inside, respectively the outside of the arm element.

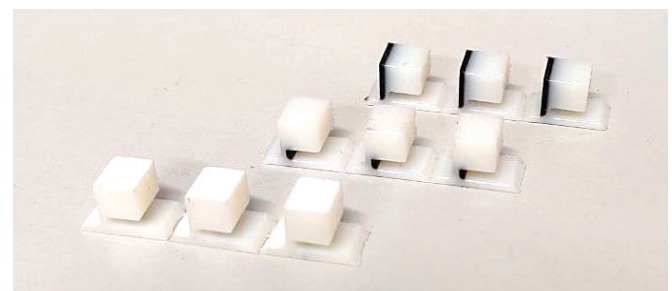


Figure 2: Polyjet printed resonators with additional rubber elements. Front: Baseline resonators, middle: rubber on the inside of the arm, back: rubber on the outside of the arm

The resonators are mounted directly on the impedance sensor, which is mounted to the shaker via a stinger. The

resonators are excited with a pseudo random signal and the response is measured with a 3D Laser-Scanning-Vibrometer. The measurement points are displayed in Figure 3. There are 25 points on the mass element and additional 5 points on the base plate. These points can be used to identify whole body modes, where the whole stinger-sensor-assembly starts to oscillate. These modes are not related to the actual resonator elements and can be neglected.



Figure 3: ABSplus resonator mounted on the impedance sensor with measurement points in min, zero and max position (right) [1]

Measurement results

From the measured surface velocities and forces the frequency response functions (FRFs) for all points are calculated and analyzed. The points on the base plate are deactivated and the average FRF of the remaining points is calculated for each resonator. In the following diagrams the averaged FRFs are grouped and color coded by geometry ID (comp. Table 1), e.g. all elements with ID1000 are orange in Figure 4. The spike at approx. 3900 Hz, which is present in all measurements of all materials and geometries, can be attributed to a whole-body mode of the sensor assembly and is not relevant.

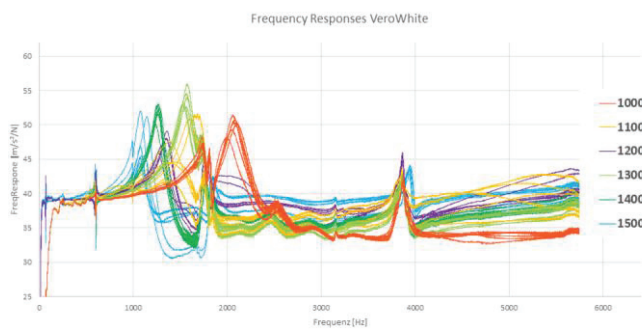


Figure 4: Averaged FRFs for VeroWhite single material resonators [1]

On the single-material VeroWhite specimen, the first mode is clearly visible on all geometries, with eigenfrequencies between 1000 Hz and 2100 Hz and amplitudes reaching 50-55 m/s²/N. Above 2500 Hz the damping ration is fairly high, and there is almost no modal behavior present. In Figure 6 a more detailed view of this frequency range is given. The red circles indicate the maxima that were identified automatically. A detailed analysis of these curves, the eigenfrequencies as well as the boxplots for the variance for all other materials and processes are presented in the previously mentioned publication [1].

The averaged FRFs for the multi material resonators are displayed in Figure 5. It is obvious that for both the inside as well as the outside variant the damping is extremely high. Since it is obvious from these measurements that these resonators are not suitable for metamaterials, not all variants of all resonators were measured.

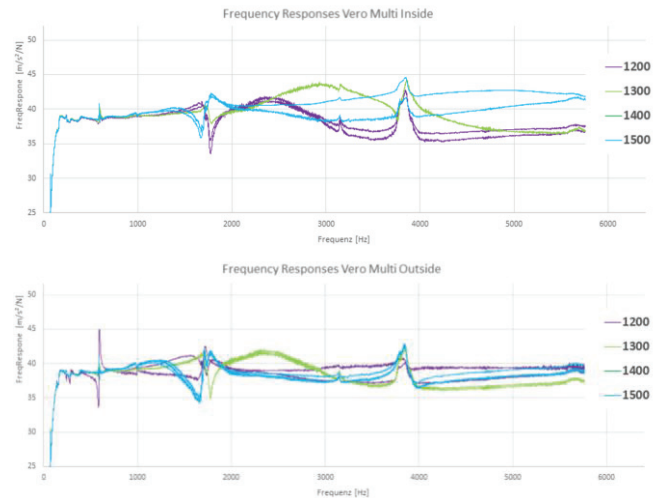


Figure 5: Averaged FRFs for multi material resonators; top: rubber component on the inside, bottom: rubber component on the outside

Figure 6 shows the detailed view of the frequency range between 700 Hz and 2300 Hz. Since there is almost no amplitude, the peak detection was not performed on the multi-material resonators.

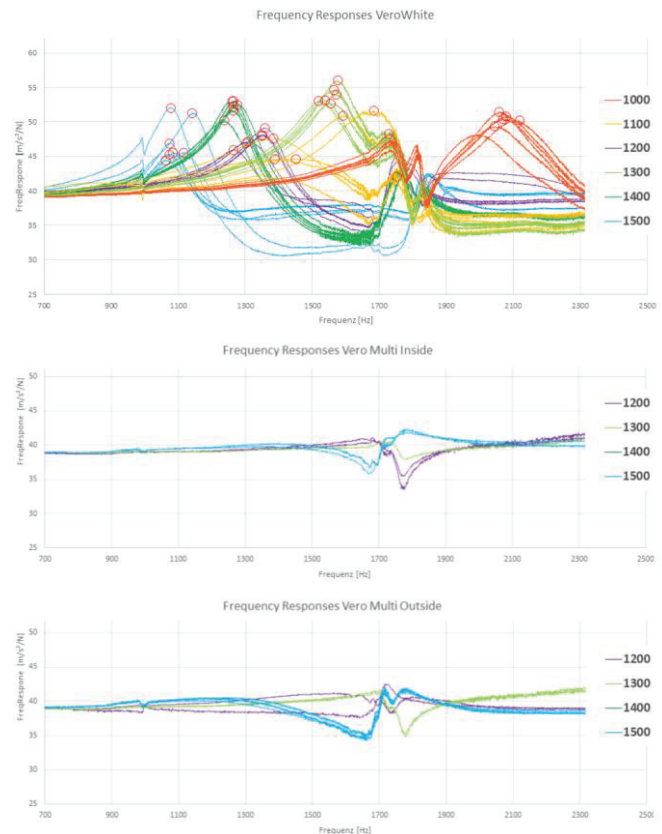


Figure 6: Detailed view of the averaged FRFs for VeroWhite single material resonators (top), multi inside (middle) and multi outside (bottom) [1]

Conclusion

The multi-material resonators with a 1mm rubber-like layer on the arm element displayed extremely high damping. The aim of the approach was to introduce a certain, relatively low amount of damping into the system, to broaden the working range of the resonators, as well as to get a first insight on the dynamic behavior of the *Agilus30* material.

There are certainly many interesting applications for this approach and multi-material parts, especially considering multi-layer housing structures or components with internal damping elements. An application for metamaterials with a reduced amount of material could still be beneficial and can be investigated in future research.

References

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