Załącznik 2
do sprawozdania z realizacji 2 etapu
projektu I.PN.10

Prezentacja pt.

Determination of the resonant frequency of the anti-vibration 3D printed metamaterial under sinusoidal and noise signal forcing - analysis of experimental and numerical results

zaprezentowany podczas

31st Conference Vibrations in Physical and Technical Systems – VIBSYS 2024

October 16–18, 2024, Poznań, Poland

Determination of the resonant frequency of the anti-vibration 3D printed metamaterial under sinusoidal and noise signal forcing - analysis of experimental and numerical results

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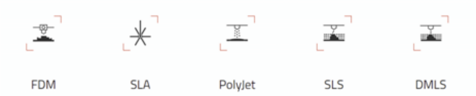
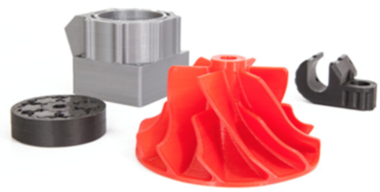
3D Printing

The current development of 3D printers makes it possible to achieve precision to tenths of a millimeter with a wide choice of materials and technology.



It is therefore worth considering them for the production of metamaterials, where the geometry of the structure plays a key role in addition to the material used.



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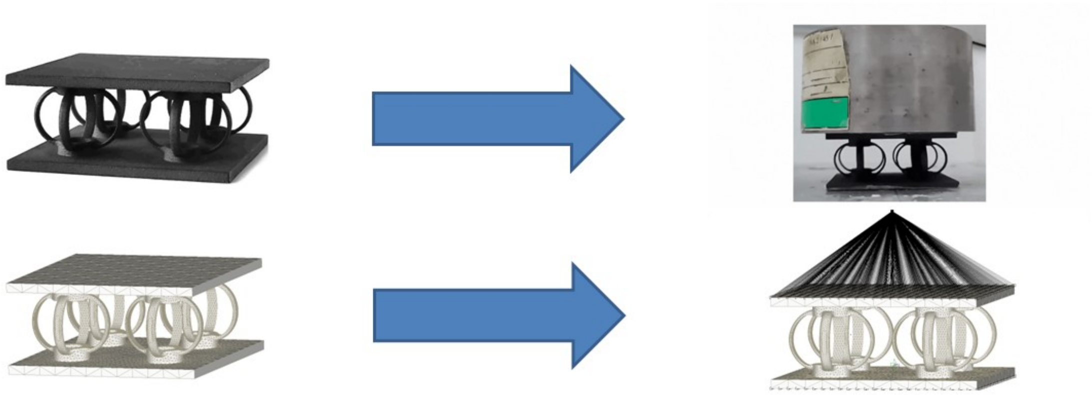
The object of research

The main objective of the research was to determine the resonant frequencies of the metastructure using numerical simulation verified with laboratory data. It was assumed that a comparison of the results of the two studies would enable an assessment of the usefulness of numerical simulations in the design of anti-vibration metamaterials.



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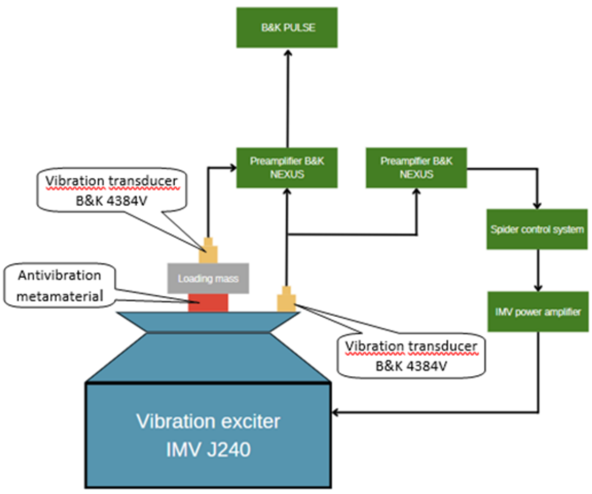
Laboratory tests



The laboratory tests were carried out on the test stand shown in the figure. During the tests, the metamaterial model was placed on a mechanical vibration exciter table.

Used excitation signals:

- Sinusoidal sweep (1 - 400 Hz; Sweep speeds: 1 oct/min and ¼ oct/min; Constant acceleration: 0.1 m/s^2)
- Filtered white noise(1 - 400 Hz; Constant PSD value of 0.001 g^2/Hz)

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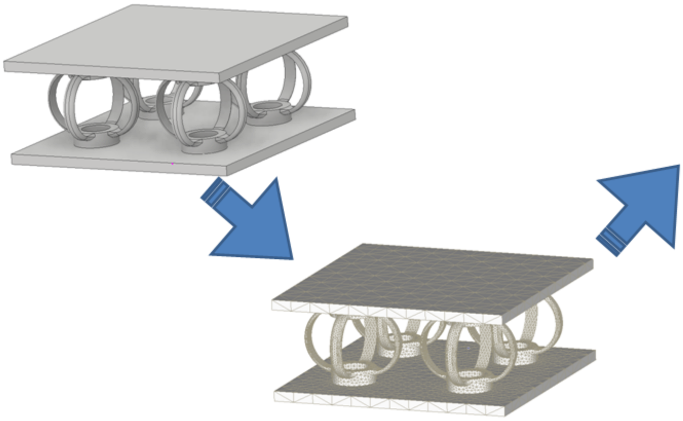
Numerical simulations

A three-dimensional model of the studied metastructure was made in Autodesk Inventor software and then loaded into Femap. The generated mesh of elements was used to perform numerical simulations.



- Modal Analysis
- Frequency Response
- Random Resposne

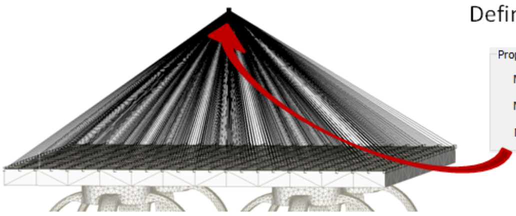
Results:

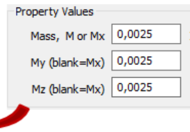
- Resonance frequency
- Vibration displacement
- Vibration acceleration
- Etc.

Numerical simulation – modal analysis

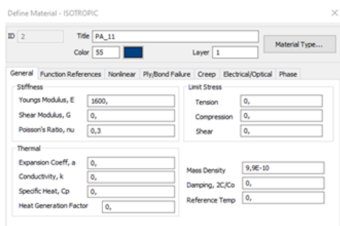
- Boundary conditions:

Defining the weight of a load:

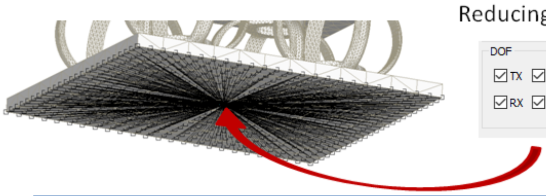


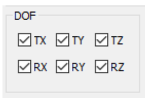


Defining material parameters:

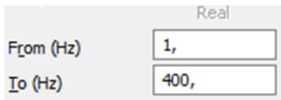


Reducing degrees of freedom:





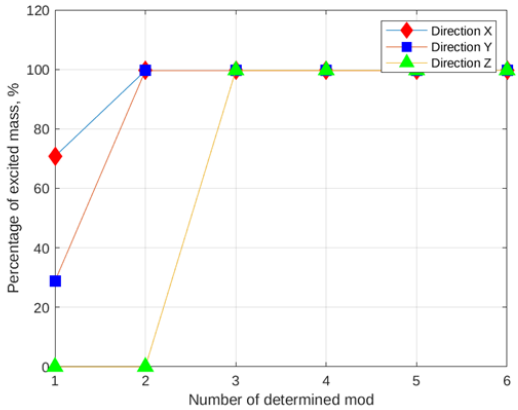
Defining frequency range:



Numerical simulation – modal analysis

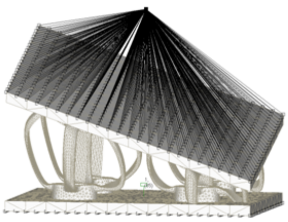
- Results of modal analysis:
  - Resonance frequencies
  - Vibration mods
  - Percentage of excited mass

Number of designated mod	Frequency, Hz
1	8.06
2	8.07
3	23.33
4	209.36
5	305.03
6	305.04

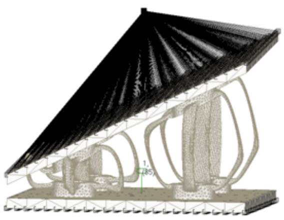


Numerical simulation – modal analysis

- Results of modal analysis:



Mod 1



Mod 2

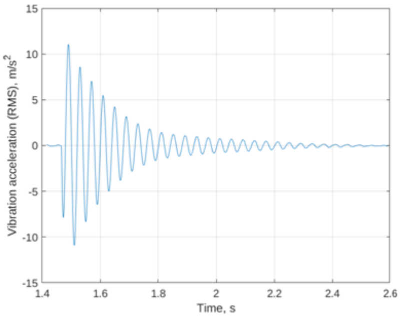
Mod 3

Analyzing the generated vibration mods of the metamaterial and the graph of the percentage of the excited mass in each direction, it can be seen that the most dangerous, in terms of possible damage, natural frequency of the tested metamaterial has a value of 23.33 Hz.

Numerical simulation – frequency response

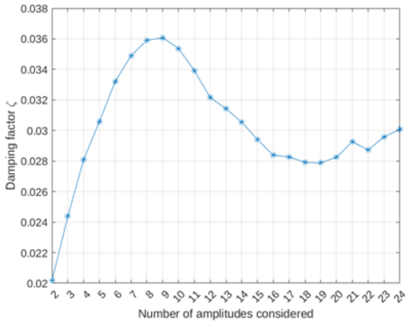
- Boundary conditions:

In order to correctly describe the behavior of the simulation model in the case of displacements, accelerations, etc., a damping factor is required. To determine the damping coefficient for the tested anti-vibration metamaterial, an additional test was carried out by recording the response to an impulse signal.



$$\sigma = \frac{1}{n} ln \frac{A_1}{A_{1+n}} = 0.189$$

$$\zeta = \frac{\sigma}{\sqrt{4\pi^2 + \sigma^2}} = 0.03$$



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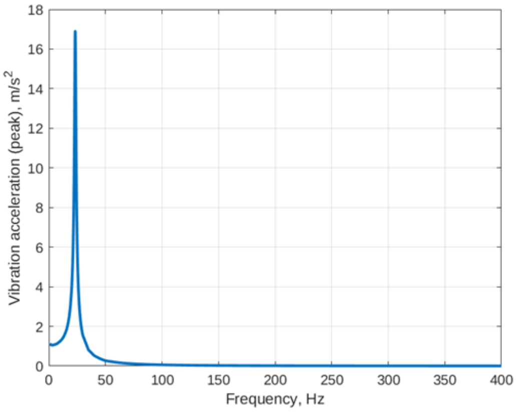
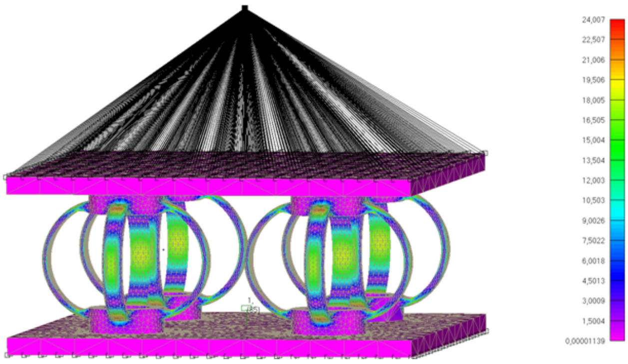
Numerical simulation – frequency response

- Results:

During the frequency response analysis, the displacements of individual mesh nodes, their accelerations, velocities and occurring stresses were determined.





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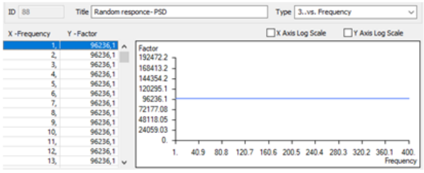
Numerical simulation – random vibration

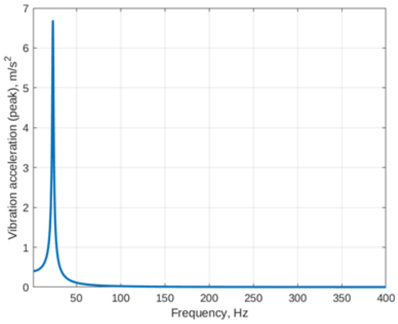
- Boundary conditions:



$$0.001\,\frac{g^2}{Hz} \approx 96246.1\,\frac{\frac{mm}{s^2}}{Hz}$$

- Results:

Random vibration analysis allows for the study of the response of a system subjected to vibrations with frequency components from the entire specified range simultaneously.



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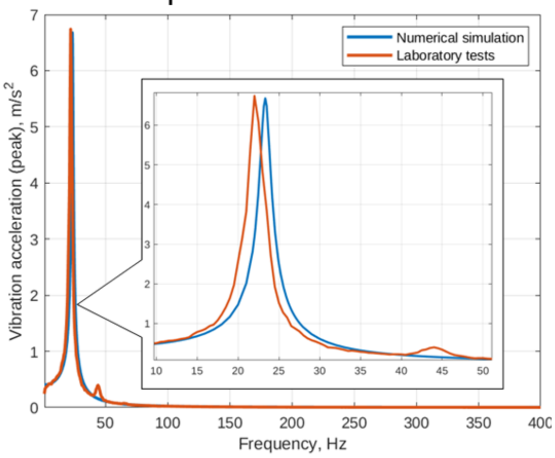
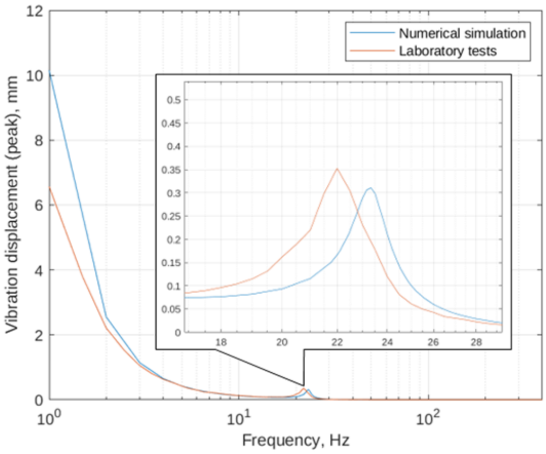
Comparison results



Vibration acceleration recorded on the payload in the case of excitation by filtred white noise signal.



Vibration displacement recorded on the payload in the case of excitation by filtred white noise signal.

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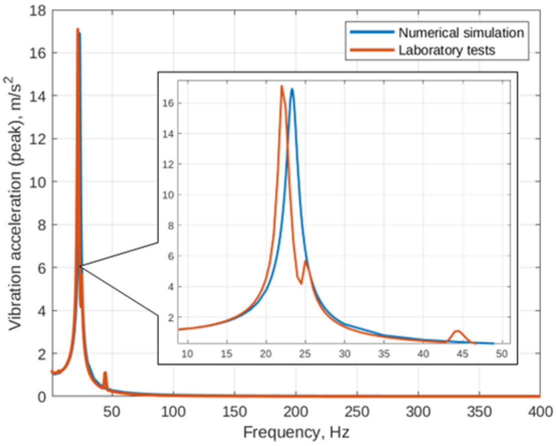
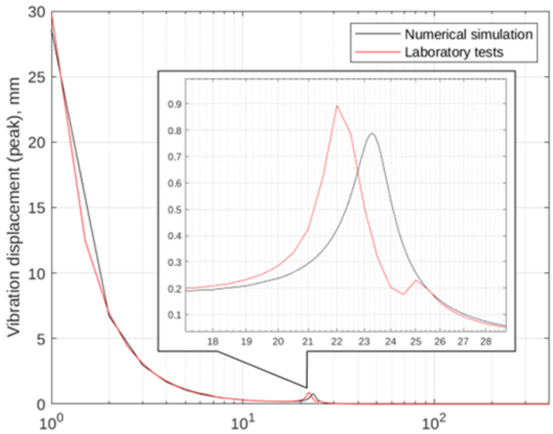
Comparison results



Vibration acceleration recorded on the payload in the case of excitation by sinusoidal sweep signal.



Vibration displacement recorded on the payload in the case of excitation by sinusoidal sweep signal.

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Comparison results

	Type of forcing signal	Resonant frequency, Hz	Vibration displacement value (peak), mm	Vibration acceleration value (peak), m/s²
Laboratory test results	Sinusoidal	22	0.89	17.1
	Filtered white noise	22	0.35	6.74
Numerical simulations results	Sinusoidal	23.3	0.79	16.9
	Filtered white noise	23.3	0.31	6.67
Relative difference, %	Sinusoidal	5.9%	11.2%	1.2%
	Filtered white noise	5.9%	11.4%	1.0%

The values of: resonant frequency, vibration acceleration recorded on the model loading mass and displacement of the loading mass, determined from simulation and laboratory tests, were compared. The resonance frequency determined on the basis of laboratory tests using a mechanical vibration exciter was 22 Hz both in the case of excitation with a noise signal and a sinusoidal signal (sweep ¼ oct/min). A similar result was obtained during numerical simulations. For both excitation signals, the resonance frequency value was 23.3 Hz.

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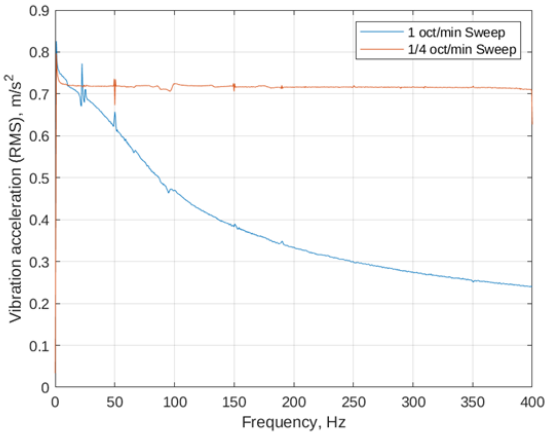
Conclusions



During the sinus sweep at a speed of 1 oct/min, it was noticed that the recorded vibration accelerations on the top of the mechanical vibration exciter differed from the expected values. The reason turned out to be that the sweep speed was too high. After setting the sweep speed to 1/4 oct/min, the recorded acceleration signal began to correspond to the expected values.

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Conclusions

- **The observed differences in resonance frequency values obtained as a result of numerical simulation and laboratory tests of the metamaterial may be influenced by many factors related to the real model and its physical parameters.**

  These include primarily: repeatability of print parameters depending on the selected print parameters such as print speed, nozzle temperature, printer table temperature, print cooling time, size of the printed object, order of applying subsequent layers; final print processing (including cleaning and removal of technological elements); storage conditions (air temperature and humidity) and others.
- **Both the values of accelerations and vibration displacements during the resonance of the tested metamaterial in individual nodes, during numerical calculations, strongly depend on the damping value.**

  As mentioned earlier, the tested system has a nonlinear nature of the damping coefficient. This makes it difficult to determine a representative value that can reflect the actual value of the damping coefficient with satisfactory accuracy.
- **During laboratory tests using a sinusoidal signal as an excitation, it was observed that the very often used in vibration tests sweep speed of 1 oct/min can cause errors in the FFT analysis using classic analysis systems.**

  In the case of the tests carried out, only a four times lower speed (1/4 oct/min) allowed for correct analysis. Conclusions from this observation can be useful both during classic vibration tests and laboratory tests.
- **Considering the practical lack of differences in the determined resonance frequency values for both excitations and small relative differences when determining the displacement and acceleration of vibrations, when testing the response of the metamaterial model to mechanical vibrations, it seems more beneficial to carry out a short test using noise excitation than a long-term test with a sweep sinusoidal signal excitation, which may additionally be a source of errors in the FFT analysis.**
- **During simulation and laboratory tests of the resonance frequencies of the tested metamaterial, good consistency of values was obtained.**

  In the case of determining the acceleration and displacement of vibrations during resonance, the differences in the obtained values were also at a satisfactory level. The type of the applied exciting signal (sinusoidal and noise) had little or no effect on the consistency of the obtained test results (as in the case of the resonance frequency values).
- **This means that the developed simulation model reflects the behavior of the tested metamaterial subjected to mechanical vibrations in a good way.**

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Thank you for your attention

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