Design of mechanically-optimised lattice structure for vibration isolation

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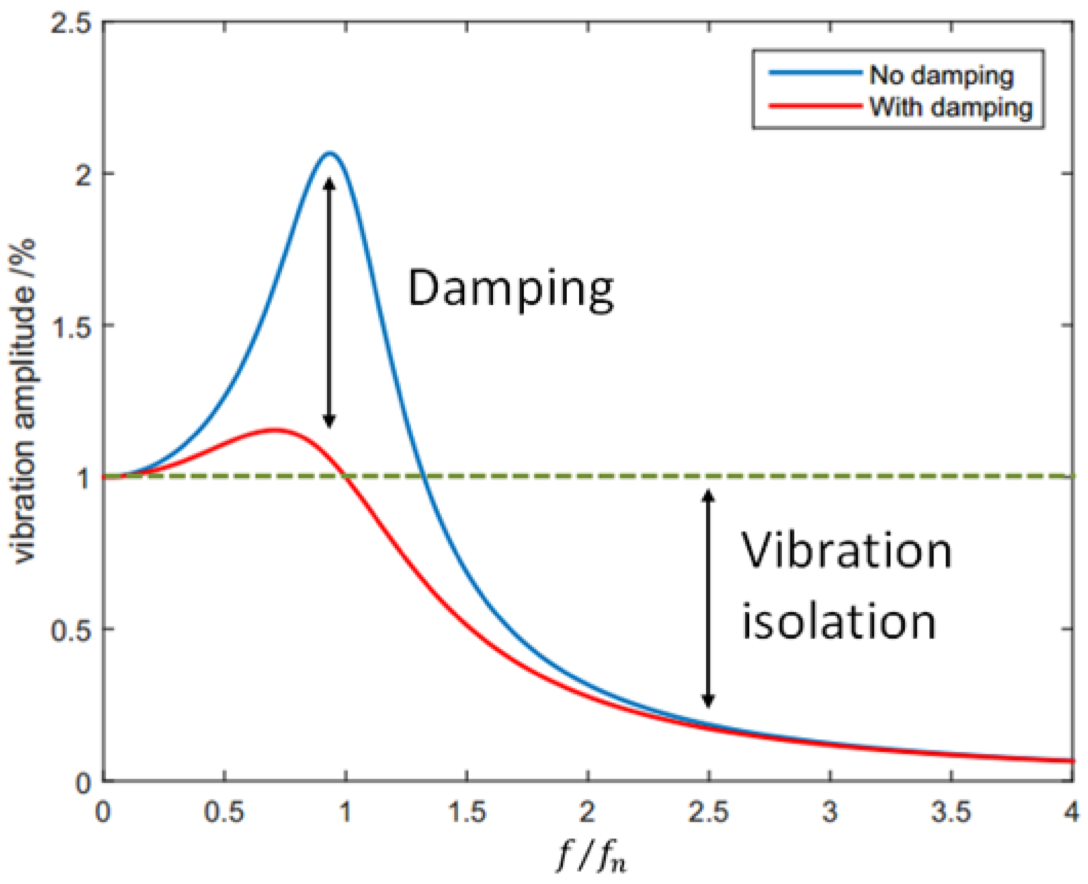
Introduction

- Additive manufacturing (AM) is limited by far fewer design constraints than conventional manufacturing
- For many applications, it is desired that structures can be isolated from external vibration. Stiff structures are often used but essentially do not isolate vibration; rather they increase the natural frequency and affect the vibration damping (FIGURE 1)
- In this study, design, analysis and experimental verification of three strut-based lattice structures focusing on vibration isolation are presented
- In addition, design parameters are proposed to compare the dynamic property of different lattices



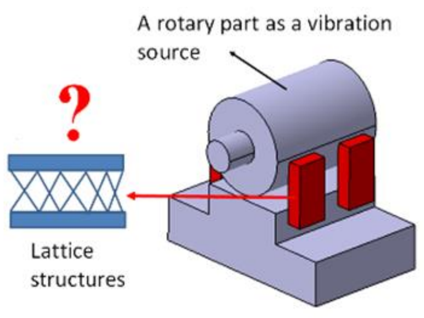


FIGURE 1. Comparison between vibration damping and isolation.

Lattice structure designs, analysis and simulation

- Three designs of strut-based lattices, both single cell and array configurations, are presented: model 1, model 2 and model 3 (FIGURE 2)
- The proposed design parameters to compare the lattices are: the total moments of inertia I_x and I_y in the $x-$ and $y-$ axes, respectively (FIGURE 3) and the Maxwell's criterion. The calculations of inertia I_x and I_y are in equation (1) and (2). The calculation of Maxwell criterion is in equation (3) and ideally equal to 0.
- To estimate natural frequency f_n, finite element analysis was carried out by using ANSYS (FIGURE 4)

$$I_{x\_i} = [\cos\theta]^2 \frac{d_s l_s^3}{12} + [\sin\theta]^2 \frac{d_s^3 l_s}{12} + l_s d_s x_s^2 \quad (1)$$

$$I_{y\_i} = [\cos\theta]^2 \frac{d_s^3 l_s}{12} + [\sin\theta]^2 \frac{d_s l_s^3}{12} + l_s d_s y_s^2 \quad (2)$$

$$|N_{strut} - 3N_{node} + 6| = c \quad (3)$$

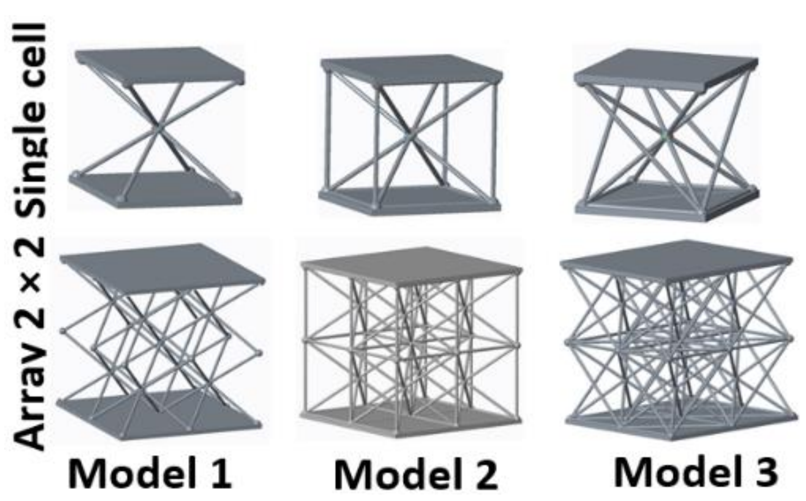


FIGURE 2. Three design of lattices. Row 1: in single cells. Row 2: in 2 × 2 × 2 array configurations.

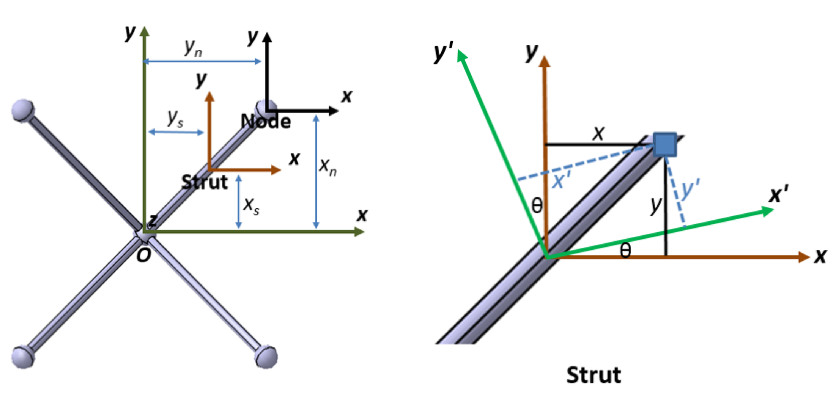


FIGURE 3. Variables used to calculate I_x and I_y.

Experimental verification

- The lattices were fabricated by laser powder bed fusion process with Nylon-12 powder (FIGURE 5)
- Impact tests were carries out to measure f_n
- The impact and compression test was carried out with two parts and three replications for each part
- The results of compression test are shown in TABLE 1 and of impact tests are shown in TABLE 2
- Comparing the simulation and experiment results, the proposed design parameters can be used as parameters for comparing designs of the lattices focusing on the vibration isolation property
- Lattice model 3 shows a good trade off between strength and natural frequency. Hence, model 3 has low natural frequency and is still able to sustain > 1 kg load (array 2 × 2 × 2 configuration)

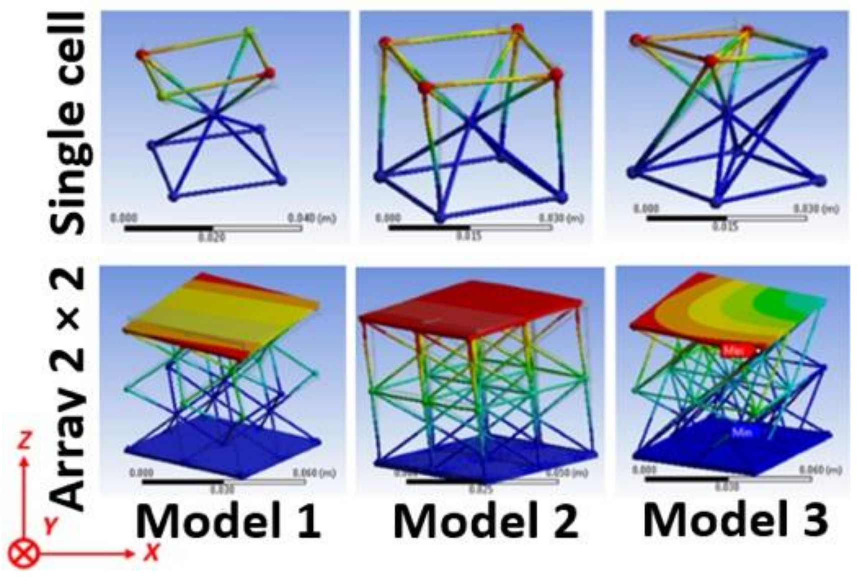


FIGURE 4. Simulation to calculate the natural frequency of the lattices.

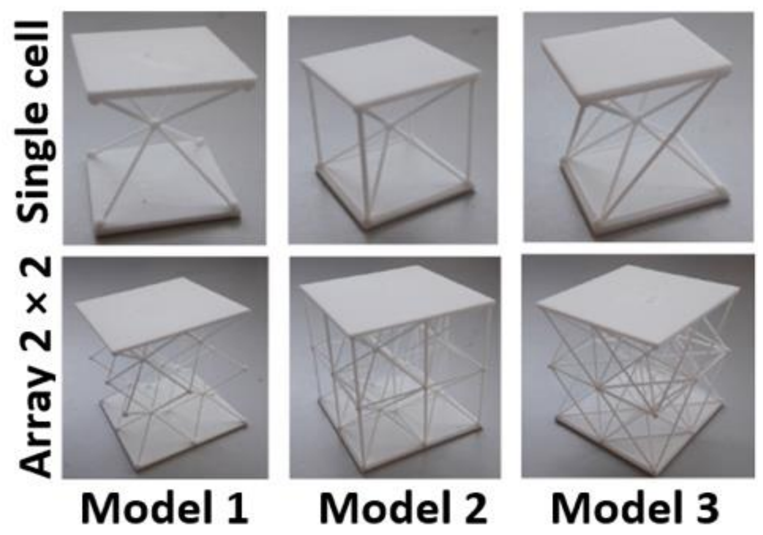


FIGURE 5. The fabricated lattices in single and array configuration.

TABLE 1. Compression test results

Model type	Max. force /N		Displacement at Max. force /mm	
	mean	± σ	mean	± σ
Model 1 single cell	2.45	0.23	0.65	0.16
Model 2 single cell	10.75	0.54	0.57	0.02
Model 3 single cell	4.32	0.30	0.42	0.01
Model 1 array 2 × 2 × 2	2.21	0.03	1.62	0.06
Model 2 array 2 × 2 × 2	19.25	0.08	0.68	0.08
Model 3 array 2 × 2 × 2	12.78	0.25	1.13	0.04

TABLE 2. Comparison of the natural frequencies of the lattice structures between FEM predictions and experiment results.

Type	Model	FEM /Hz	Experiment/Hz (mean value ± σ)	difference /%
Single Cell	Model 1	146.52	162.79 ± 8.67	9.99
	Model 2	287.03	308.09 ± 10.67	6.84
	Model 3	165.48	199.96 ± 9.61	17.24
2 × 2 × 2 Array	Model 1	47.55	49.77 ± 10.16	4.42
	Model 2	530.81	464.79 ± 47.41	14.20
	Model 3	324.79	320.70 ± 23.92	1.28

Conclusion

- The study presents design, analysis and experimental verification of three lattices focusing on vibration isolation
- The proposed design parameters can be used to compare the dynamic properties of different lattices and are very fast to compute (compared to simulation or experiment).

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