Dynamic Tailoring of Interlocking Metasurfaces (ILMs)

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Introducing Us

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What are Interlocking Metasurfaces (ILMs)?

- Strength
  - Strong
  - Weak

- Ease of assembly
  - Easy
  - Hard

- Welds
  - Permanent
  - Non-permanent

- Bolts
- Adhesives
- Traditional latches
What are Interlocking Metasurfaces (ILMs)?

Interlocking metasurfaces (ILMs) are a type of surface design that allows for easy assembly and non-permanent fixation. They offer an alternative to traditional latches, bolts, and adhesives, providing a balance between strength and ease of assembly.

- **Strength**: Interlocking metasurfaces can be designed to be either strong or weak, depending on the application.
- **Ease of Assembly**: Can be easy or hard, depending on the design and user preference.

In summary, Interlocking Metasurfaces (ILMs) offer a versatile and flexible solution for assembly and fixation needs.
What are Interlocking Metasurfaces (ILMs)?

- Composed of an array of interlocking unit cells
- Wide variety of designs, many of which have already been studied
- Interested in transmissibility of different designs (ratio of output acceleration to input acceleration under vibration)

Young et al., Mater. Des., 2023
How do the geometric parameters affect the response under vibration?

- Optimize the geometry using results from tension tests
- Characterize the response using transmissibility plots from steady state modal dynamics

Bolmin et al., JOM, 2023
Studied Designs

- Sliding T Slot - Carson
- Sliding V Slot - Lindsay
- Split Arrowhead - Andrew

Bolmin et al., JOM, 2023
What Parameters Matter?

**Sliding T-Slot**

**Parameters (mm)**
- \( W1 = [2.2, 3.8] \)
- \( R1 = [0.1, 0.9] \)
- \( R2 = [0.1, 0.9] \)

**Constraints (mm)**
- \( R1 + R2 < 1 \)
- \( R2 < 0.5 \times W1 - 1 \)
- \( W2 = 4 - W1 \)

**Sliding V-Slot**

**Parameters (mm)**
- \( RW = [1.8, 2.8] \)
- \( CV = [0.2, 0.4] \)

**Split Arrowhead**

**Parameters (mm)**
- \( W0 = [0.4, 0.7] \)
- \( W1 = [0.71, 0.81] \)
- \( \theta0 = [30, 55] \)
- \( \theta1 = [25, 35] \)
- \( \theta2 = [2, 8] \)
FEA Model Setup

- Type of Model (Linear Solvers)
  - Static, General
  - Frequency
  - Steady State Modal Dynamics
- No friction or damping
- “Hard contact” normal behavior
- Parts are in perfect contact (Tension Tests)
- Boundary Conditions
  - Fixed Base
  - X-Symm on sides of mass block
  - Z-Symm on front and back of mass block
- Parametric Optimization

Material Properties – Vero White (photocurable polymer)
- Density – 1174 kg/m³
- Youngs Modulus – 2.06 GPa
- Poison’s Ratio – 0.4
- Yield Strength – 46 MPa
Optimization Results

- Percent decrease in maximum Von Mises stress from original design to optimized design

15.2%

58.4%
Quasi-Static Tension – 3D

- Attempted to quickly test the validity of the 2D models by running a 3D test to compare
- Stress profiles are similar, but values are slightly off
- 2D model interprets design to be as thick as the block, which is not true
S.S. Modal Dynamics – 2D

- Performed frequency analysis
  - Interested in mode with vertical displacement
  - Experimented with different configurations: 1x1 unit cell, 5x1 array

- Performed steady-state dynamic analysis on original shape

- Introduced 25 mm mass blocks to model to reduce rigidity of structure

5x1 array of V-slot with natural frequency of 6269.3 Hz
## Frequencies of Mode of Interest (Hz)

<table>
<thead>
<tr>
<th></th>
<th>T-Slot</th>
<th>V-Slot</th>
<th>Split Arrowhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D</td>
<td>6795</td>
<td>6269.3</td>
<td>229.12</td>
</tr>
<tr>
<td>3D</td>
<td>6674</td>
<td>-</td>
<td>180.83</td>
</tr>
</tbody>
</table>

### 2D Simulation
![2D Simulation Diagram](image1.png)

### 3D Simulation
![3D Simulation Diagram](image2.png)
S.S. Modal Dynamics – 3D

- Introduced new configuration: 5x5 array
  - 5x5 array produced similar frequencies to 5x1 array → only use 5x1 array for simulations, less computationally expensive

- Generated plots for optimized shape for comparison with experimental data
S.S. Modal Dynamics – Experimental Setup

• Triaxial accelerometer, sample, and shaker are mounted on top of each other respectively

• Printed designs in 5x5 array

• Printed 1 original design and 2 optimized designs
  • Ran 3 sine sweeps from 50 – 8000 Hz for each sample
  • Repeatable runs
S.S. Modal Dynamics – Experimental Results
Discrepancies Between Printed Parts and FEA

- CAD models and FEA models did not have exact same measurements
- Boundary conditions and edge geometry have a large effect on the dynamics of the sample
- Contact Properties
- V-slots
  - Tolerances affected accuracy of transmissibility plots

On average, each dimension in our Abaqus model was larger than the printed model

Large gaps appeared between some of the parts

On the edges of the model, there are significant deformations that occur
Conclusion

• Cells parameterized for tension had varying effects on the frequency response

• Our FEA models do not accurately predict the frequency response

• For the sliding T-slot and Split Arrowhead, the 5x1 vs. 5x5 frequency analysis is virtually identical
Future Work

• Test model strength in shear

• Explore different optimization schemes
  • Enforce more constraints that prevent the cells from disengaging
  • Use an optimization function dependent on yield stress and failure instead of maximum Von Mises stress

• Optimize shape to increase natural frequencies

• Model more accurate FEA model
  • Change contact properties
  • Better accommodate for gap between parts
  • Create more realistic boundary conditions
  • Recreate FEA model to match geometric parameters of printed part
EXTRA SLIDES
S.S. Modal Dynamics – Experimental Results

**T-Slot**

- Initial Design, Sample 1
- Optimized Design, Sample 1
- Optimized Design, Sample 2

**Split Arrowhead**

- Initial Design, Sample 1
- Optimized Design, Sample 1
- Optimized Design, Sample 2

**V-Slot**

- Initial Design, Sample 1
- Optimized Design, Sample 1
- Optimized Design, Sample 2
Some designs fracture, some disengage
- Optimizing the design can create sufficient compliance in the parts for disengagement
- Not optimizing for strength at failure