A REVIEW OF SHOCK MITIGATION TECHNIQUES

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INTERIM TECHNICAL REPORT
Shock mitigation methods (i.e., techniques for attenuating high amplitude stresses with high frequency content) are of great importance in defense applications. This presentation focuses on classifying and critically evaluating these techniques using categories based on the physical mechanism responsible for the mitigation. For example, crushable structures such as automotive "crumple zones" effectively attenuate single shock loads via irreversible deformation (plasticity), but they can also amplify subsequent shock loads. Other mitigation mechanisms include phase transformations, viscous dissipation, wave mode conversion, and stress wave redirection. A “bottom-up” approach is used to define shock mitigation performance, beginning with simple 1-D models of stress wave transport through a multiple component system. Transmission and reflection performance of the mitigating material(s) are defined, calculated, and verified using simple experiments. Finally, approaches for improving the overall mitigation performance using topological optimization will be discussed.
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A Review of Shock Mitigation Techniques

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Outline

• **Introduction**
  – Motivation of Shock Mitigation Technology

• **Review of Shock Mitigation Techniques**
  – Current approaches

• **Shock Mitigating Metamaterials**
  – Characteristics of Mechanical Metamaterials
  – Computational framework
  – Optimization

• **Summary**
Introduction

- Impact and shock is relevant to many fields
  - Crash testing
  - Defense

- Common features
  - Impulse stress waves
    - Short rise time
    - High frequency
    - High amplitude
  - Wide range of damage
    - Sensor resonance
    - Material failure
    - Fatigue, etc.
Motivation and Approach

Motivation:
- Improve the survivability of fuzes and electronic subsystems in high shock environments

Approach:
- Design, Develop, and Demonstrate shock mitigation technology
Mechanical Deformation

- Crumple Zones
  - e.g., Crushable Cellular Material [1]
  - Low and Intermediate Velocity Impact
  - Mainly Inelastic → One Shot

Viscoelastic

- Polyurea
  - energy dissipation from hard and soft domains [2]
- Polysulfide
  - mechanical isolator [3]


Superelastic

- NiTi → Shape Memory Alloy (SMA)
- Strength of metal and flexibility of plastic
- Dissipated energy from phase transformations
- Kink and crush Resistant
- Large amount of recoverable deformation

• Biomimetic – Biologically inspired

• Mimics constrained layer damping mechanism found in the woodpecker skull

Mechanical Metamaterials

- Allows one to tailor the physical properties of composite systems at the continuum scale, even to the point in which unphysical properties emerge

- Mechanical properties are determined by the shape, interfaces, and sizes of the composing materials

1-D Mechanical MetaFilter

- Given a material, determine layer size which filters mechanical waves in a desired frequency range


Theoretical Framework

- **Transfer matrix method**
  - Assume infinitely periodic layered material consisting of a repeated unit cell
  - Solve elastodynamic equation for the unit cell consisting of \( n \) layers
  - Use periodicity of the material to compute band structure

\[ T_j = \begin{bmatrix}
\cos(k^{(j)}d^{(j)}) & (1/Z^{(j)})\sin(k^{(j)}d^{(j)}) \\
-Z^{(j)}\sin(k^{(j)}d^{(j)}) & \cos(k^{(j)}d^{(j)})
\end{bmatrix} \]

Computational Design

- Couple continuum level simulation with optimization algorithms to obtain the optimum design parameters.
- Shock Filter Design: fitness function involves a weighted penalty for a passband in a specified frequency range.
- Design parameters: layer thickness, number of layers, density, elastic modulus.

Potential MetaFilter

- 10 layer unit cell of Polyethylene (HDPE) and Aluminum layers on the order of mm-μm
Next Step: Experimental Validation

Diagram showing a gas gun setup with striker bar, input bar, sample, output bar, and input/output gauges.

Graphs showing transmission and reflection of pulses, with amplitude and time (µs) on the x-axis and y-axis.

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Summary

• Shock mitigation is a difficult task
  – High Frequency, High Amplitude Stress Waves
  – Wide range of shock induced systems failure

• Many current technologies and techniques exist
  – Mechanical Deformation
  – Viscoelastic
  – Superelastic
  – Constrained Layer Damping
  – Biomimetic
  – …

• Mechanical metamaterials provides a robust framework to develop shock mitigating technology
  – Properties are determined by the shape, interfaces, and sizes of the composing materials
  – Computational design for specific application
“Opinions, interpretations, conclusions, and recommendations are those of the authors and not necessarily endorsed by the United States Air Force or the National Research Council.”
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