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Evaluating the Use of Energy Response Spectra for Determining the Relative Severity of Machining Operations

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Carl Sisemore and Vit Babuška
Sandia National Laboratories
Albuquerque, NM

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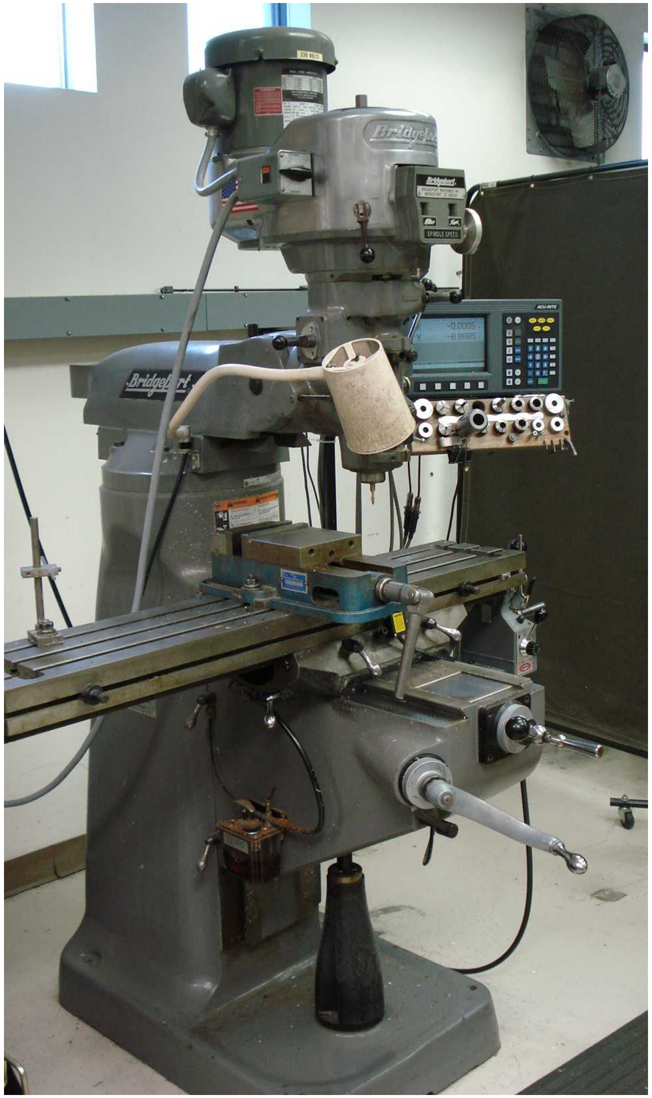
Outline

- Reason for Evaluating Machining Operations
- Overview of Energy Spectra
- Analysis of Sample Weld Data
- Fatigue Damaging Dissipated Energy Spectra
- Component Removal Example
- Conclusions

Introduction

- Recent interest in removing welded-in components from larger assemblies
  - Inspection and testing
  - Possible reuse
- Requires significant effort to dissect down to component and cut through welds
- Testing and reuse both require the component to be removed cleanly and with low probability of damage



Energy Spectra Overview

- Energy balance equation

$$E_I = \int_0^z M\ddot{z}(t)dz + \int_0^Z C\dot{z}(t)dz + \int_0^z Kz(t)dz$$

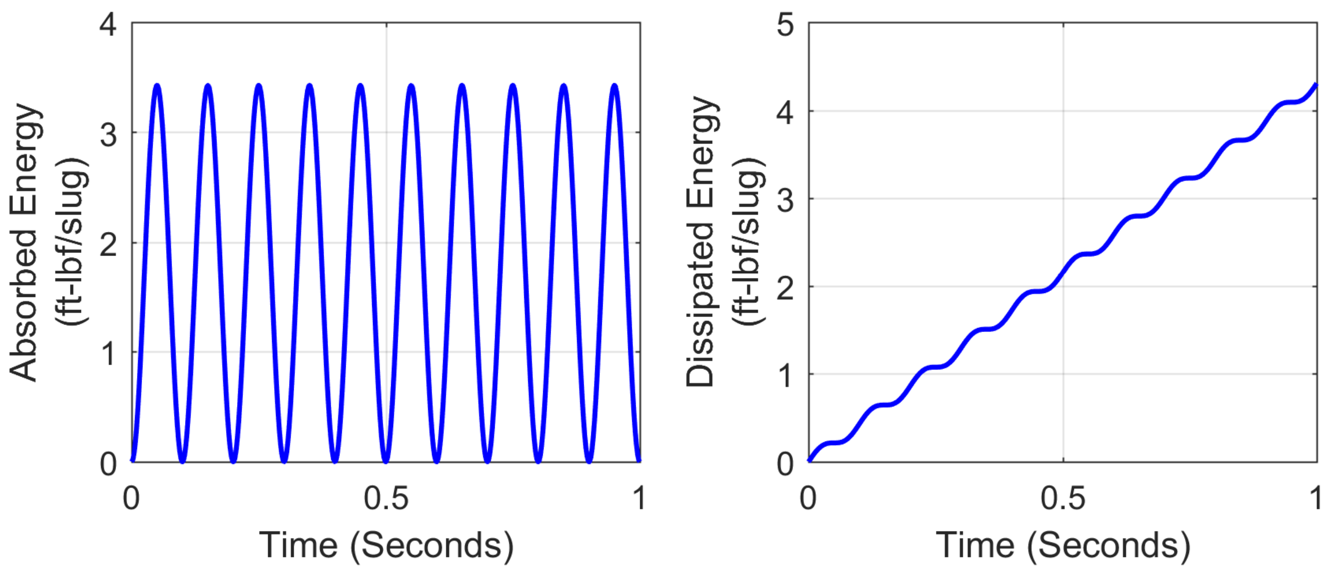
- Usually rewritten for integration with respect to time by substituting $dz = \dot{z}dt$ gives:

$$-\int_0^T \ddot{x}(t)\dot{z}(t)dt = \int_0^T \ddot{z}(t)\dot{z}(t)dt + 2\zeta\omega \int_0^T \dot{z}(t)^2 dt + \omega^2 \int_0^T z(t)\dot{z}(t)dt$$

- The dissipated energy in the above equation is the only squared term and is thus always monotonically increasing

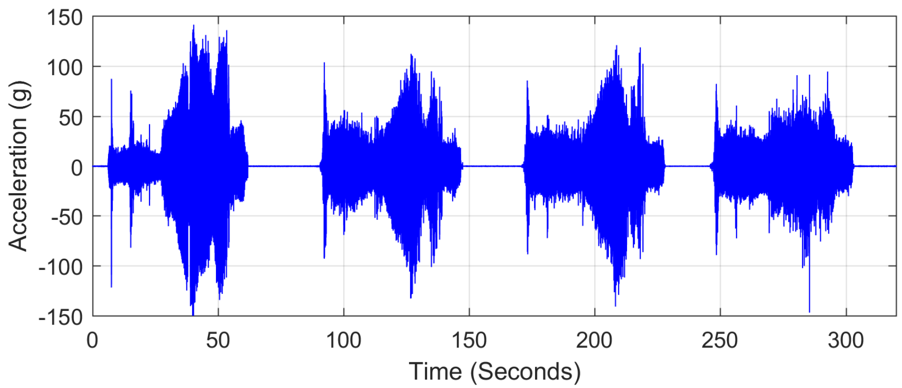
Dissipated Energy per Cycle

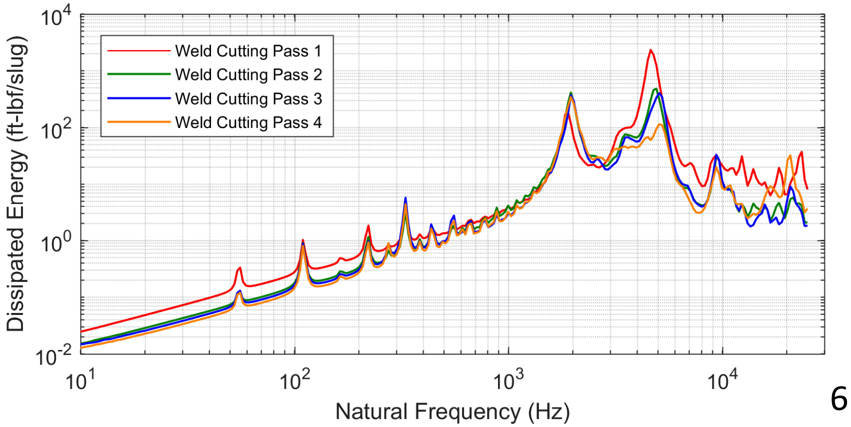
- Strain (absorbed) energy and kinetic energy vary as the system deforms
- Dissipated energy, in contrast, accumulates with every strain cycle
    - Example assuming a simple 5Hz sinusoidal waveform



Sample Weld Machining

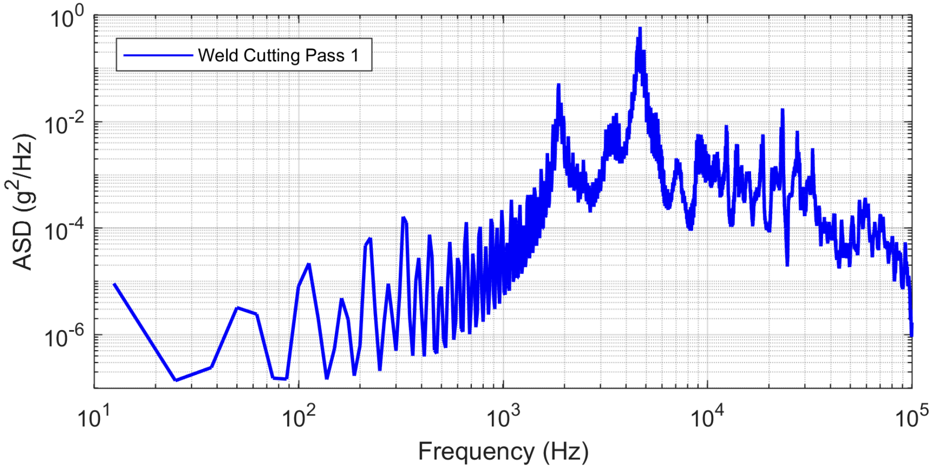
- Sample weld cutting operation to evaluate data collection methods
  - 2 flute cutter, 9.4 in/min feed rate, same cutting depth per pass
  - Nominally 55 seconds per pass
  - 4 passes to cut through
- Non-stationary response during pass – varies between passes
- Dissipated energy spectrum is similar for each pass

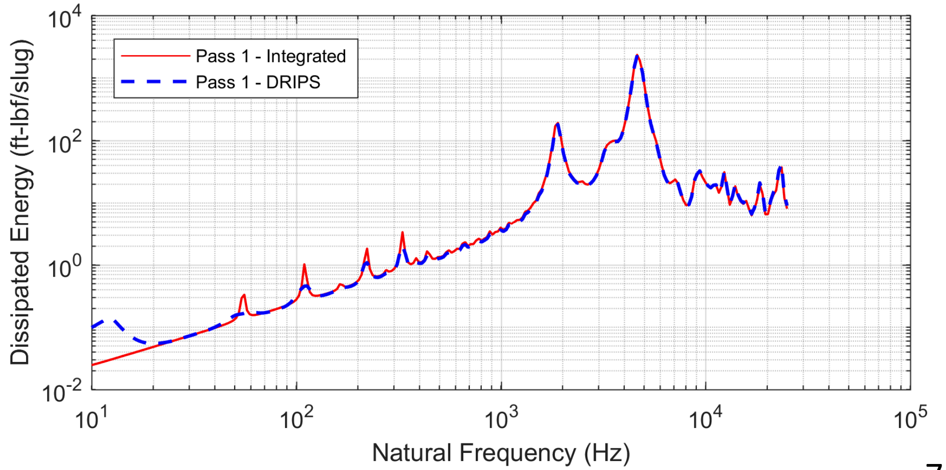




Energy Spectra from Weld Data

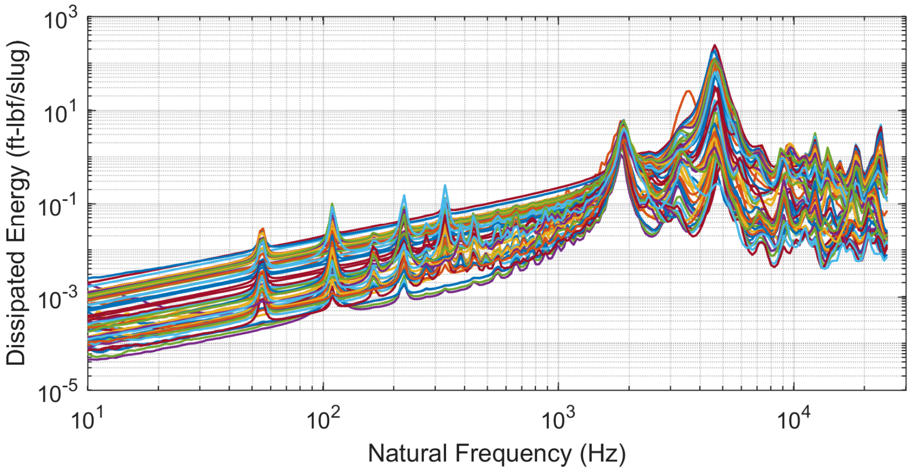
- Dissipated energy spectra can be calculated using the integrals or from an ASD using the Deformational Response Input Power Spectrum (DRIPS) method
- Wanted to verify that both methods were giving comparable answers
- ASD calculated using Welch's Method with averaging



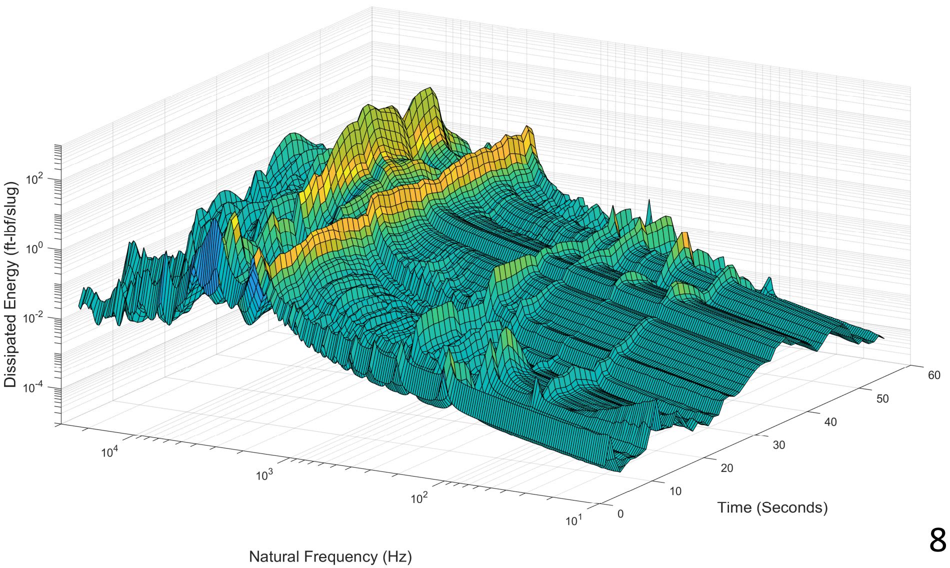


Calculated Energy by Segment

- Divided pass one data into half-second non-overlapping segments and analyzed
  - Dissipated energy is additive so this is permissible



- Significant variation seen throughout the time history
  - Some peaks are more stable
    - 1900Hk
  - Some peaks show significant variation across time
    - 4600Hz



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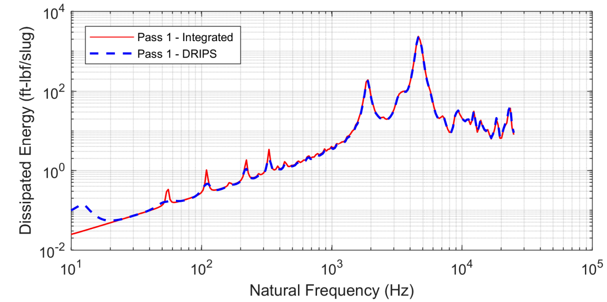
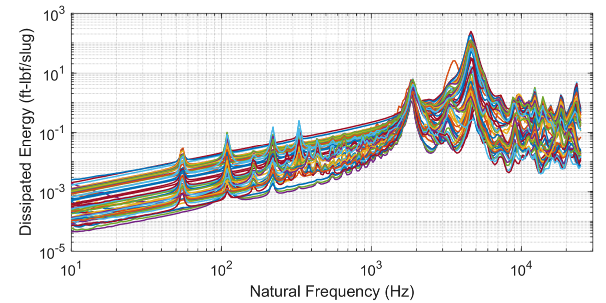
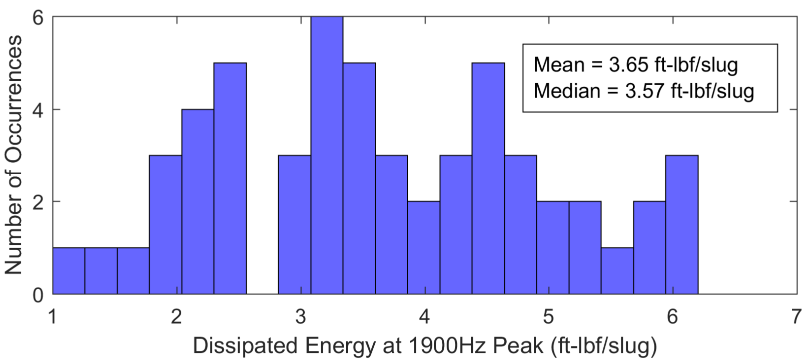
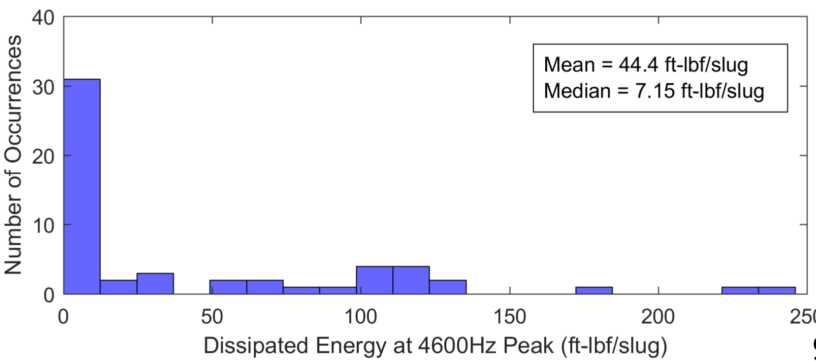
Dissipated Energy Peaks

- Total dissipated energy from full record
  - 1900Hz peak = 191 ft-lbf/slug
  - 4600Hz peak = 2340 ft-lbf/slug
- Significantly different from mean or median from segmented analysis
  - 1900Hz peak median = 3.57 ft-lbf/slug
  - 4600Hz peak median = 7.15 ft-lbf/slug
  - 55 total segments 1.0 sec each









Application of Miner's Rule

- Miner's Rule is defined for number of cycles at a stress level

$$D = \sum_{i=1}^{k} \frac{n_i}{N_i}$$

- Dissipated energy has no knowledge of stress or cycle count
- Propose a fatigue damaging dissipated energy spectrum
  - Based on Miner's rule methods
  - Start with one-second dissipated energy spectra
  - Scaled using fatigue damage coefficients
  - Summation of scaled one-second spectra

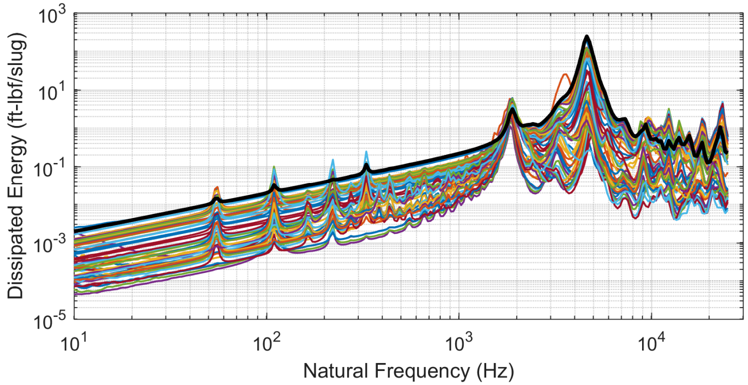
$$\frac{E_{D_2}(\omega)}{E_{D_1}(\omega)} = \left(\frac{T_1}{T_2}\right)^{2b}$$

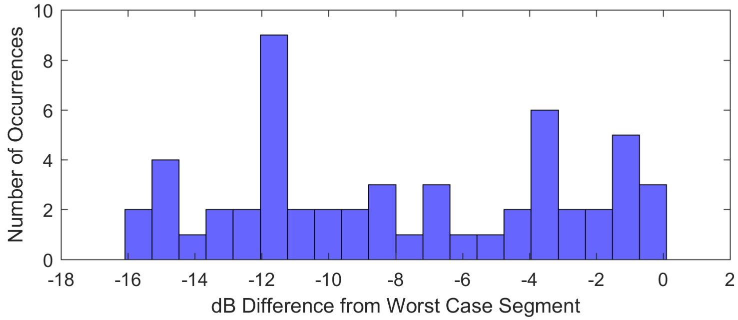
$$D = \sum_{i=1}^{k} s_f n_i$$

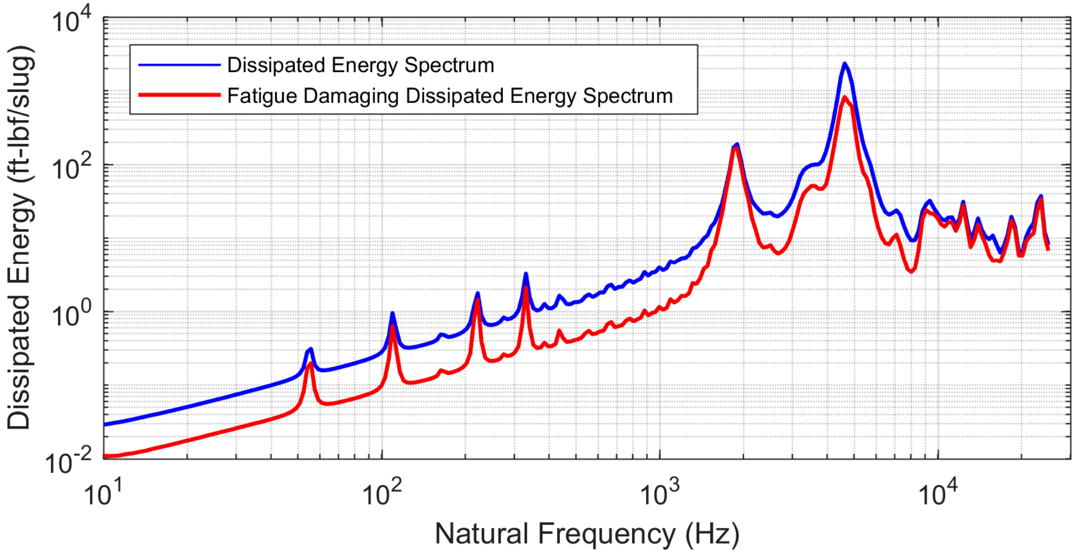
$$s_f = 10^{\frac{1}{2b}\log_{10}\left(\frac{E_{D_i}}{E_{Dmax}}\right)}$$

Fatigue Damaging Dissipated Energy

- Scales each one-second segment using fatigue damage coefficient and sums scaled results
- Most segments are far below the worst case segment







- Miner's rule method results are on average 7.8dB below the traditional method

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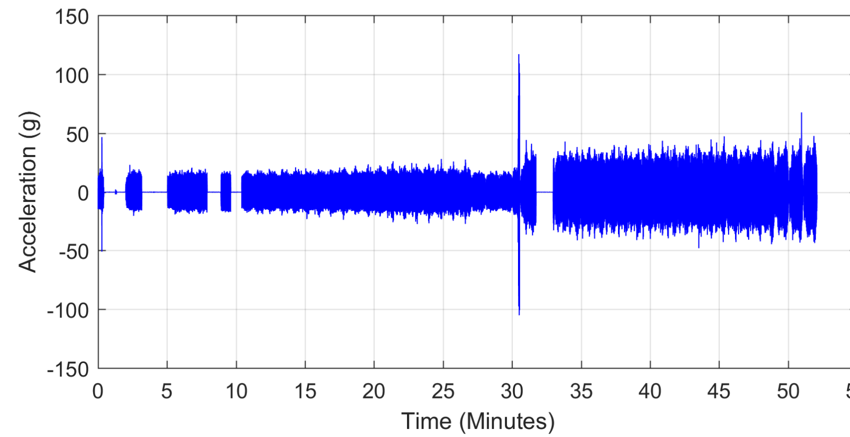
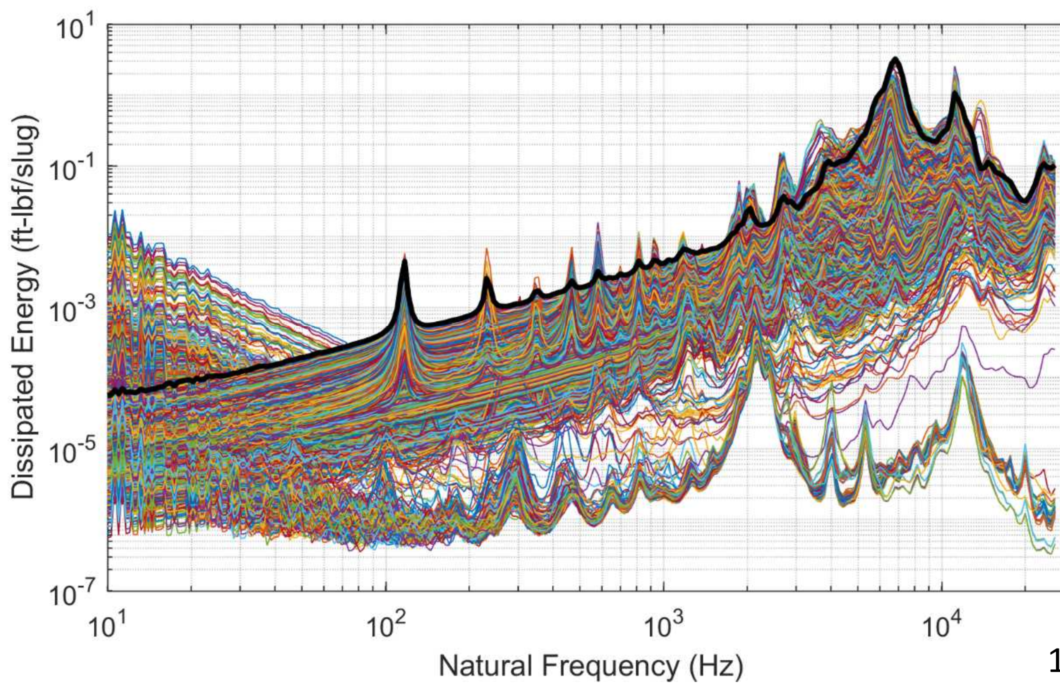
Example from a Real Part

- Unit machined to remove a particular sub-component
  - CNC machining
  - 52 minutes cutting time

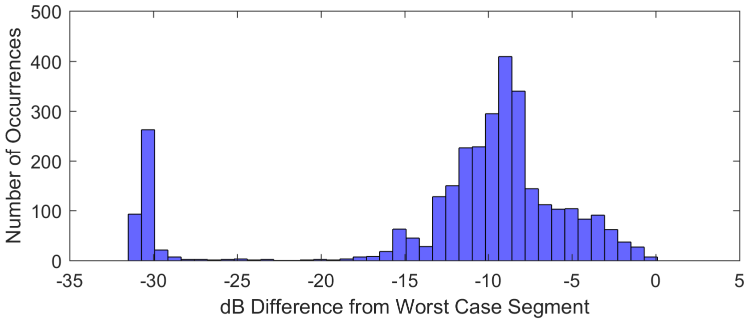


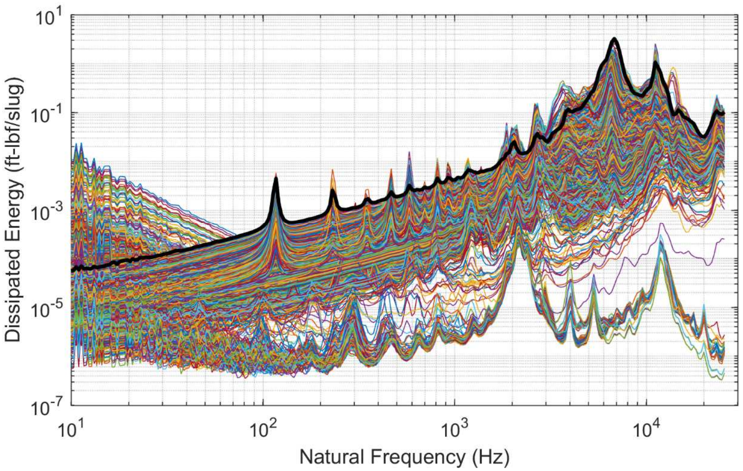
- Analysis performed in one second segments
  - 3121 total segments
  - Worst case segment highlighted

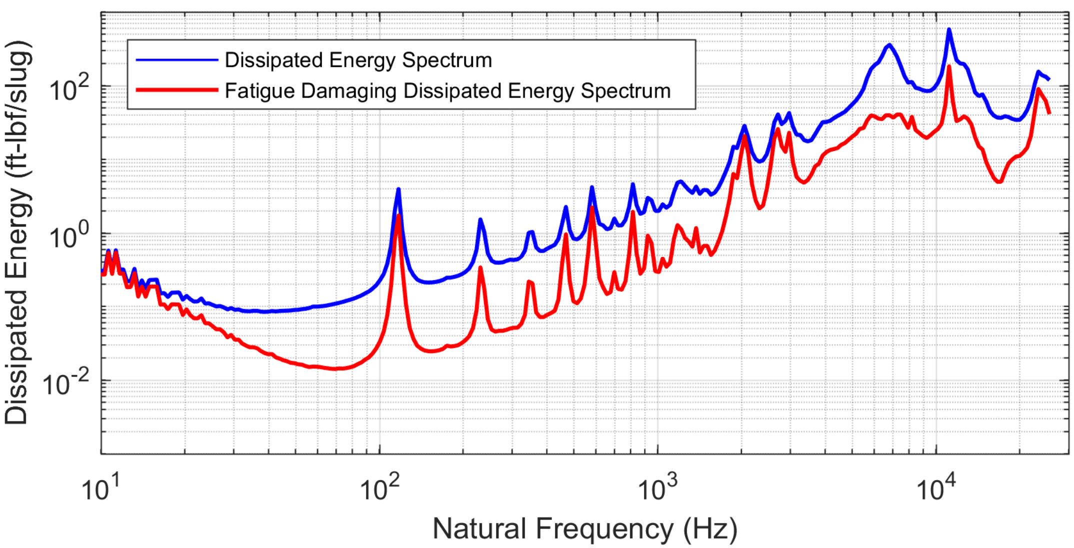


Dissipated Energy Results

- Here again, most one-second segments are far below the worst case segment







- Miner's rule method results are on average 12.1dB below the traditional method

Conclusions

- Dissipated energy spectrum linearly increases with time but fatigue damage is logarithmic

- Methodology proposed here attempts to correct the relationship between dissipated energy and damage potential

- Further research needs to be performed to verify the applicability of the proposed methodology