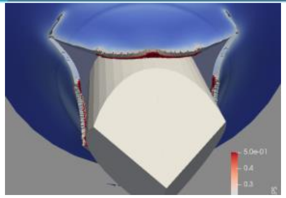
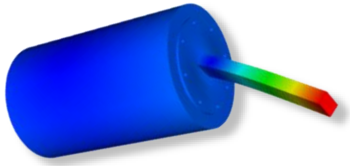
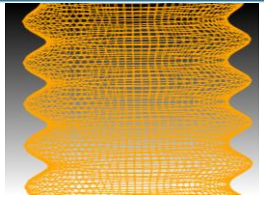
Electrical Chatter and Modal Response of Pin-Receptacle Contacts in Oil







THE UNIVERSITY OF NEW MEXICO

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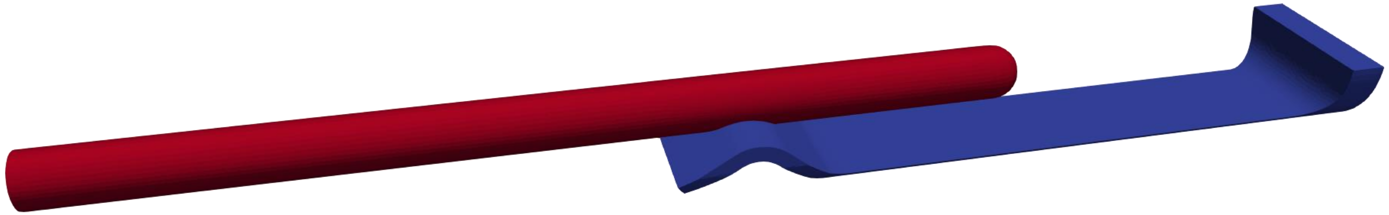
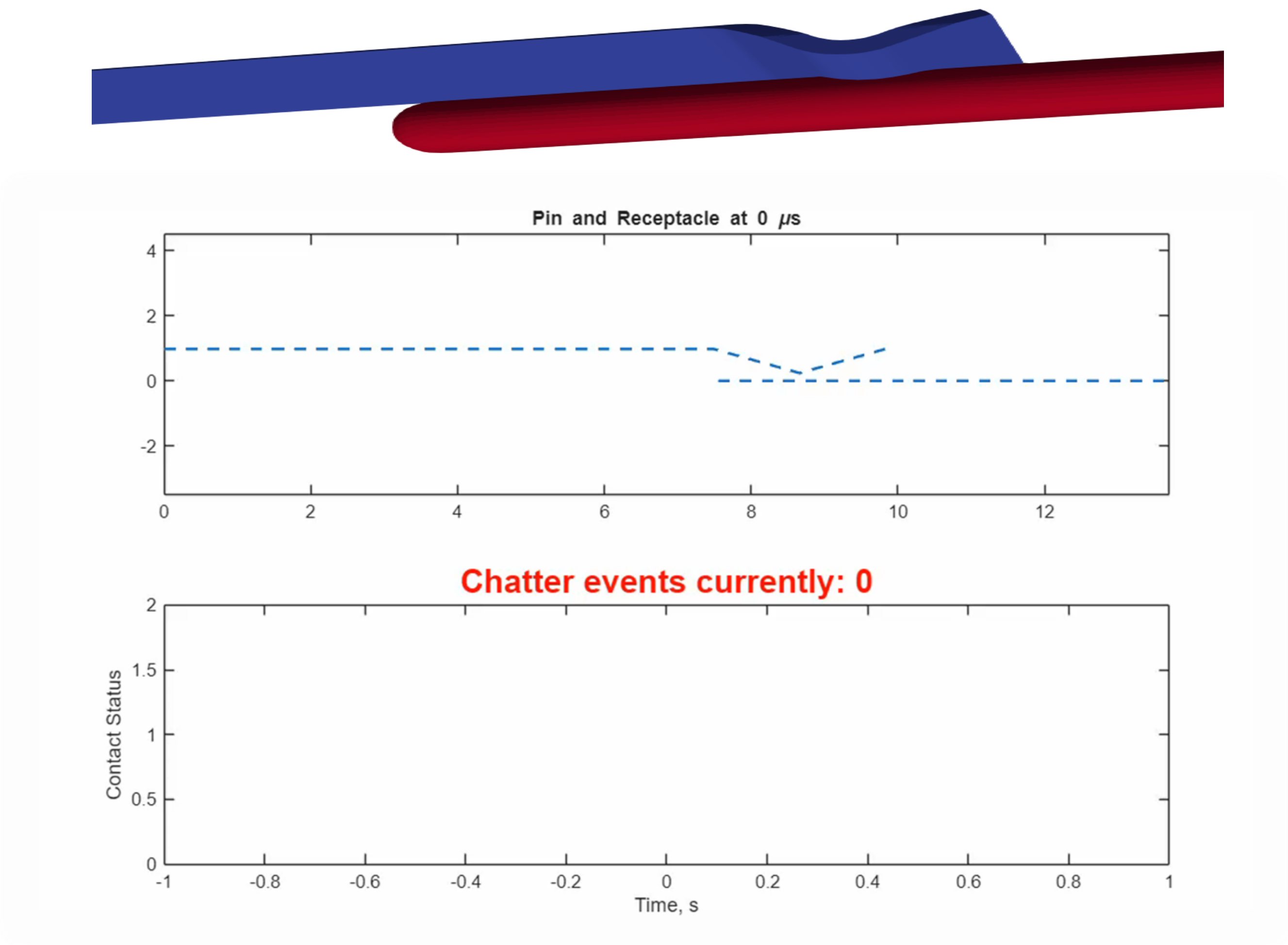
Background

- Pin-receptacle systems are used in many engineering applications to selectively allow / prevent the transmission of electrical signals.
- When exposed to vibration or shock, these connections experience abrupt changes in electrical resistance; this phenomenon is referred to as electrical chatter.
- Chatter degrades signal quality across this type of electrical pair.
- This is a continuation of previous NOMAD studies in 2019, 2023, and 2024 with a focus on investigating chatter of electrical connections in oil.



Objective: Characterize electrical chatter in a switch submerged in oil.

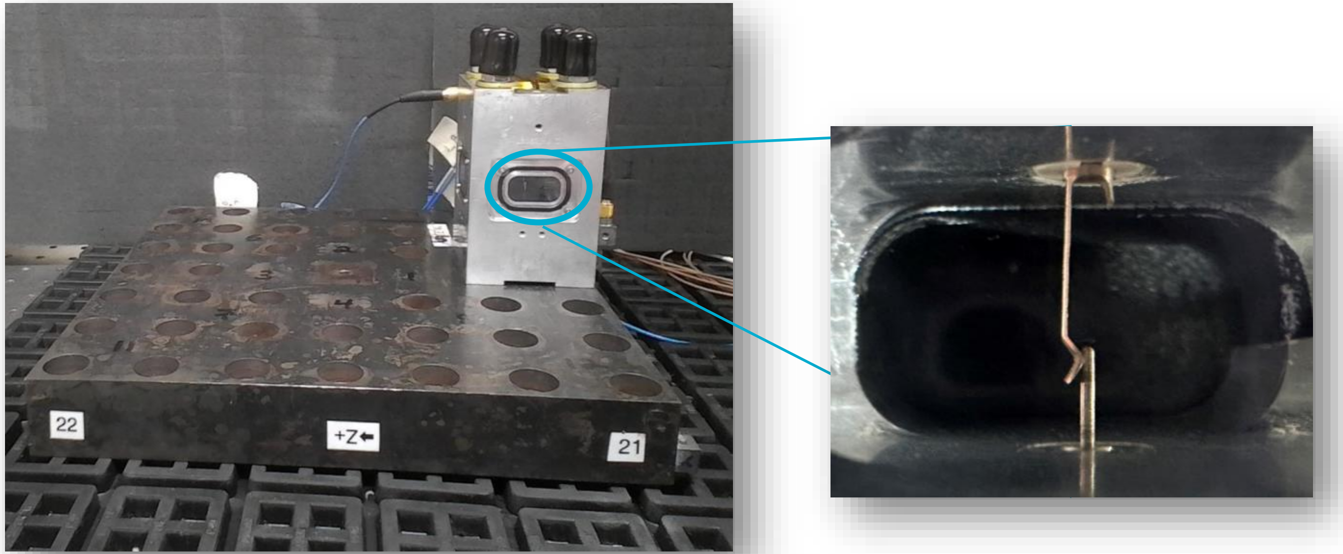
What is Chatter?

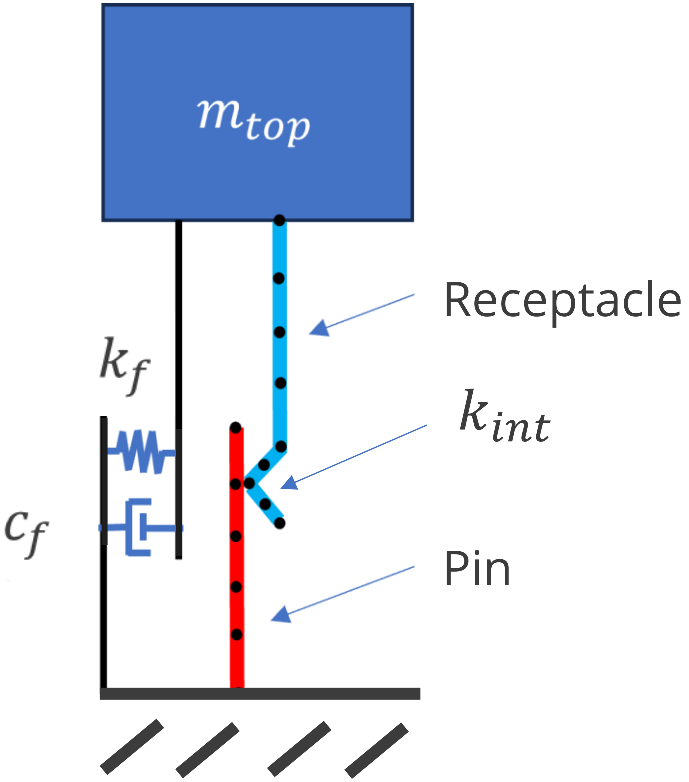


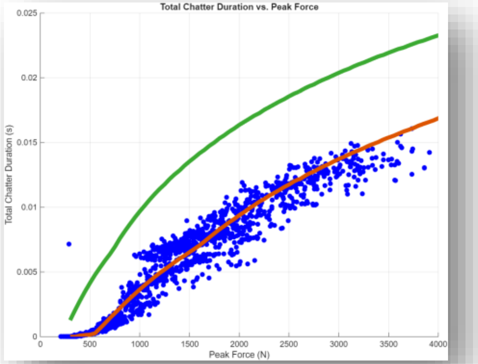
The number of chatter events and duration affect signal quality.

Project Goals

- Collect chatter measurements with the pin-receptacle in air and oil.
- Understand the effect of model parameters on chatter prediction (parametric studies).
- Select model parameters to accurately match the experimental chatter results in air and oil.





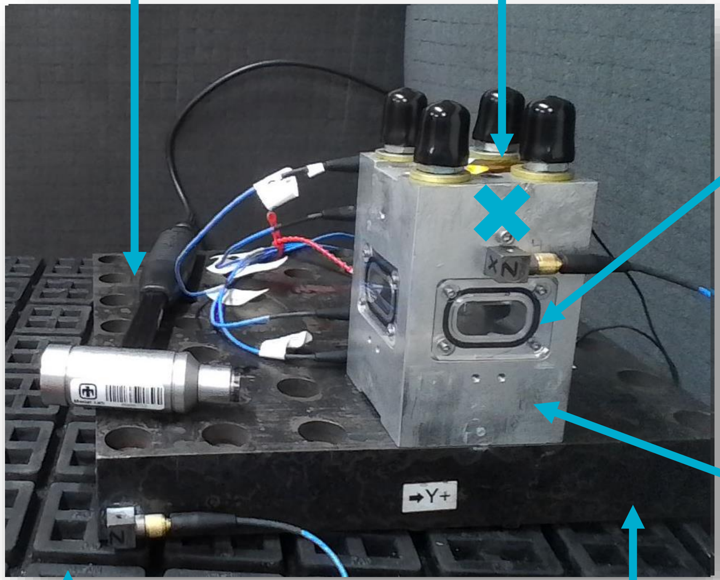


Experimental Methods

Experimental Setup

Modal hammer

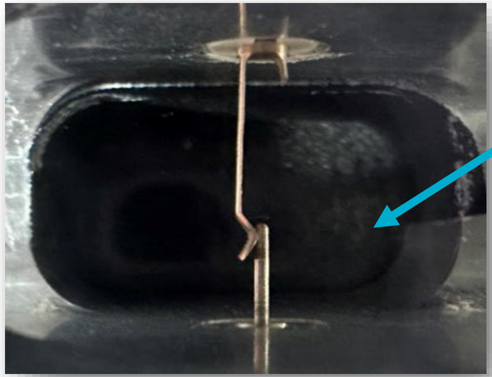
Impact location



Test fixture

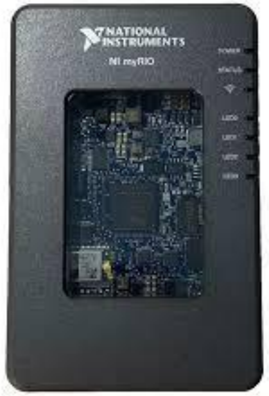
Rubber pad for isolation

Plate to simulate fixed base



Krytox (GPL101)

Receptacle and pin



Chatter events recorded with myRIO

Polytec LDVs for pin and receptacle

Accelerometer and LDV data recorded with Siemens SCADAS

Experimental Properties

Material Properties

	Pin	Receptacle	Oil
Material	Paliney 7	NeyoroG	Krytox GPL 101
Modulus (GPa)	124	94.1	-
Poisson	0.36	0.41	-
Density ($\frac{g}{cm^3}$)	11.8	15.9	1.9
Viscosity (cSt)	-	-	17.4

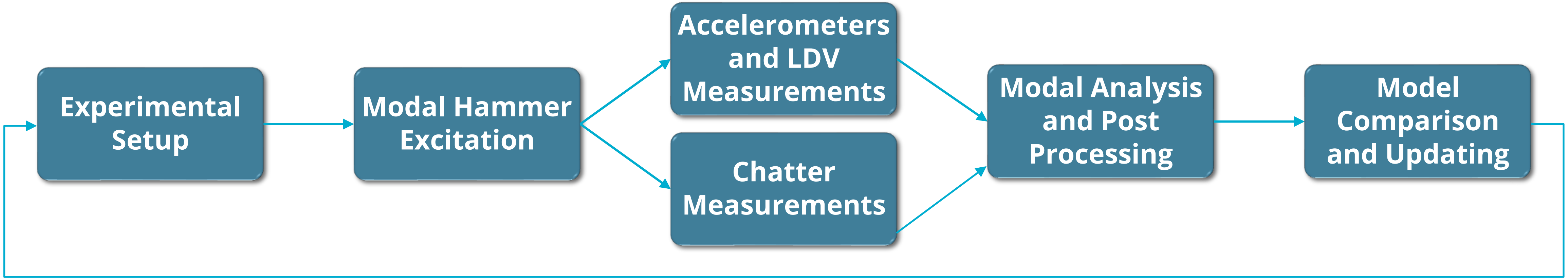
DAQ Properties

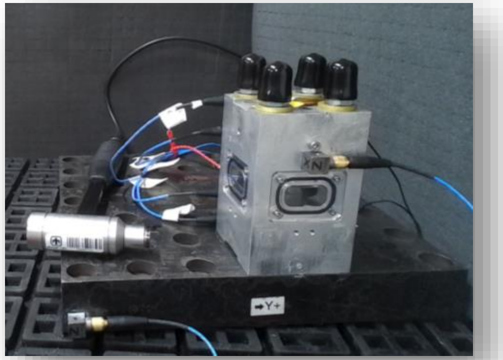
	MyRio	LDV	Accel	SCADAS
Resolution	25 ns	<0.04 $\frac{\frac{\mu m}{s}}{\sqrt{Hz}}$	±500 g pk	5 Hz

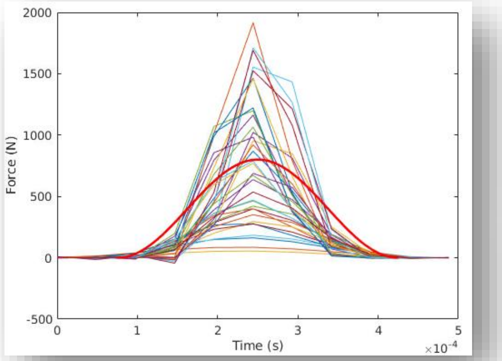
Environmental Parameters

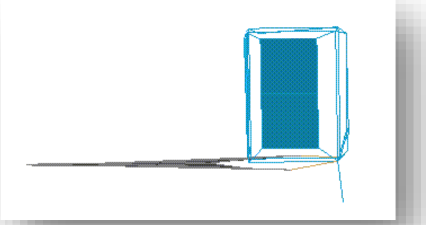
Temperature (°F)	70
Humidity (%)	30-50

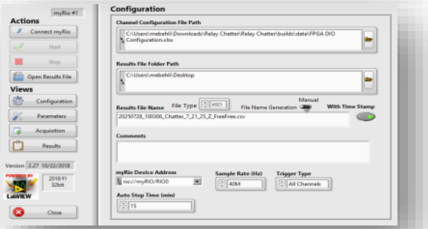
Experimental Method

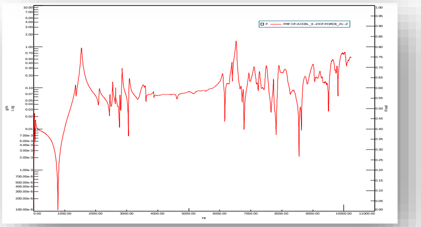


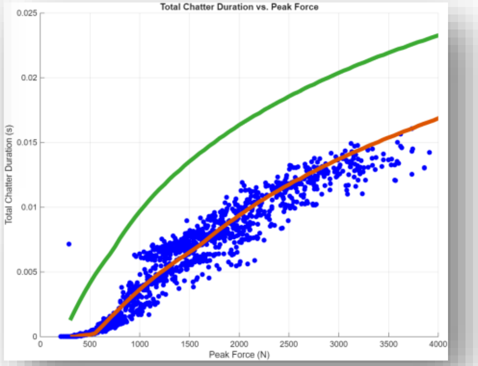






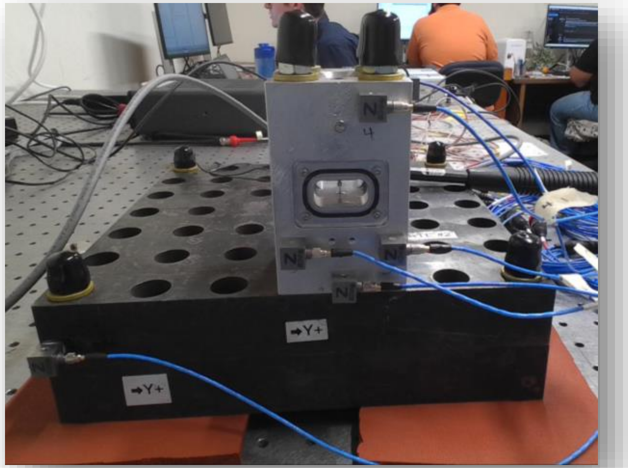


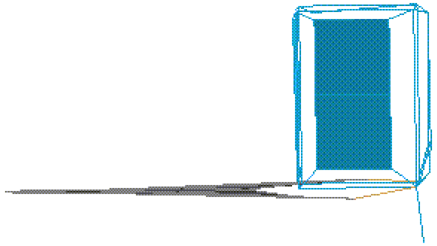




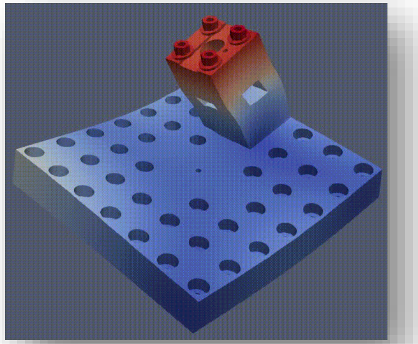
Chatter and acceleration measurements sync automatically.

Fixture Boundary Condition

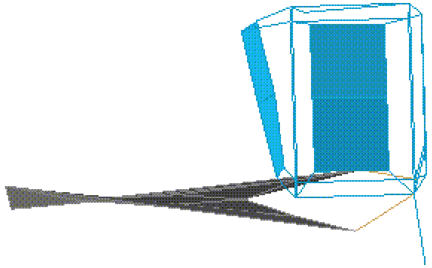




Single plate
1356 Hz Mode



Both plates elastically deform, but the bolted connections in the two plate setup added a potential source of error

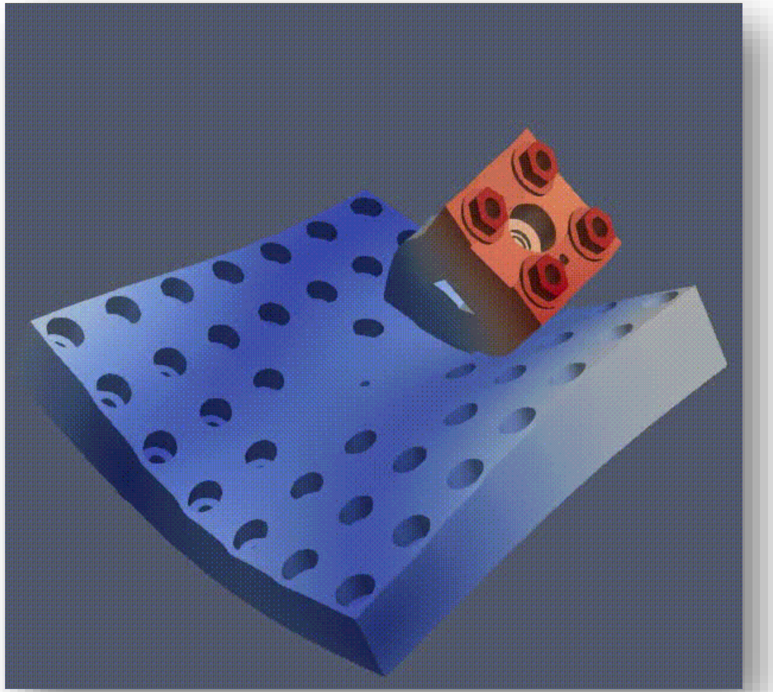


Double plate
1156 Hz Mode

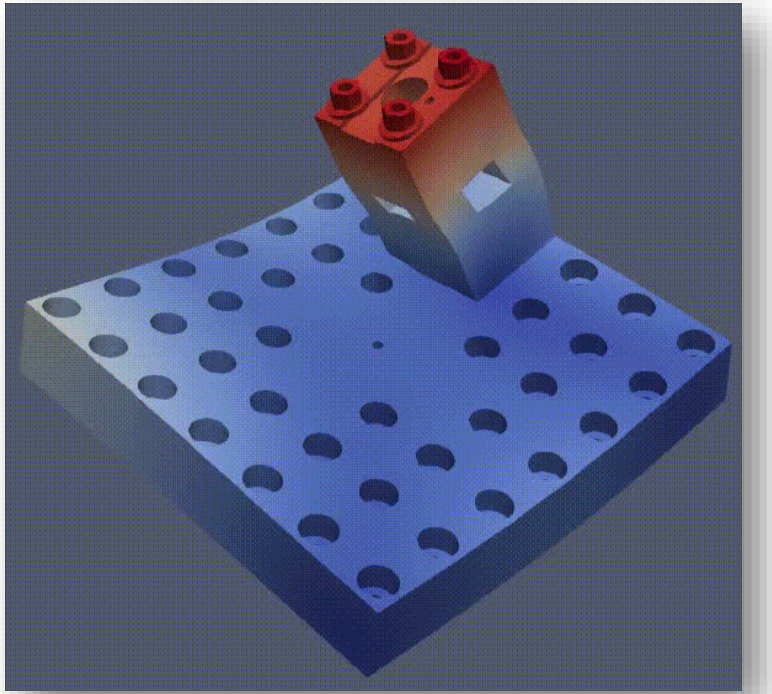
Fixture was bolted to a plate to mimic a fixed-base boundary condition

The 1-plate setup was a reasonable approximation for the model despite its elasticity.

Fixture Boundary Conditions 3D FEM



1st Fixture bending mode, 1496 Hz

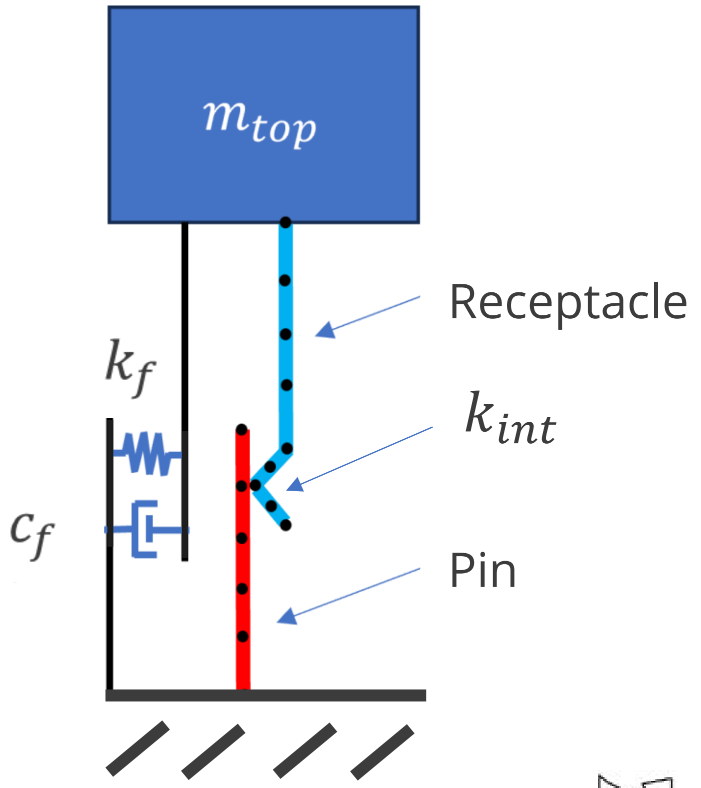


2nd Fixture bending mode, 1556 Hz

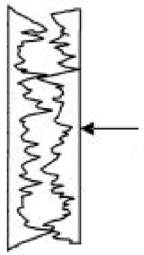
3D FEMs were primarily used to understand the test setup boundary condition and the first bending mode and natural frequency.

2D Model

- Model consists of 17 Euler-Bernoulli beam elements
- Top mass m_{top} represents effective mass for the primary bending mode of the fixture.
- Interface spring k_{int} models Hertzian contact between the pin and receptacle as $F_{nl} = k_{int}\delta^{3/2}$.
- Fixture spring k_f models the bending stiffness of the fixture.
- k_f, k_{int}, c_f are modified to account for oil and other boundary conditions using experimental data

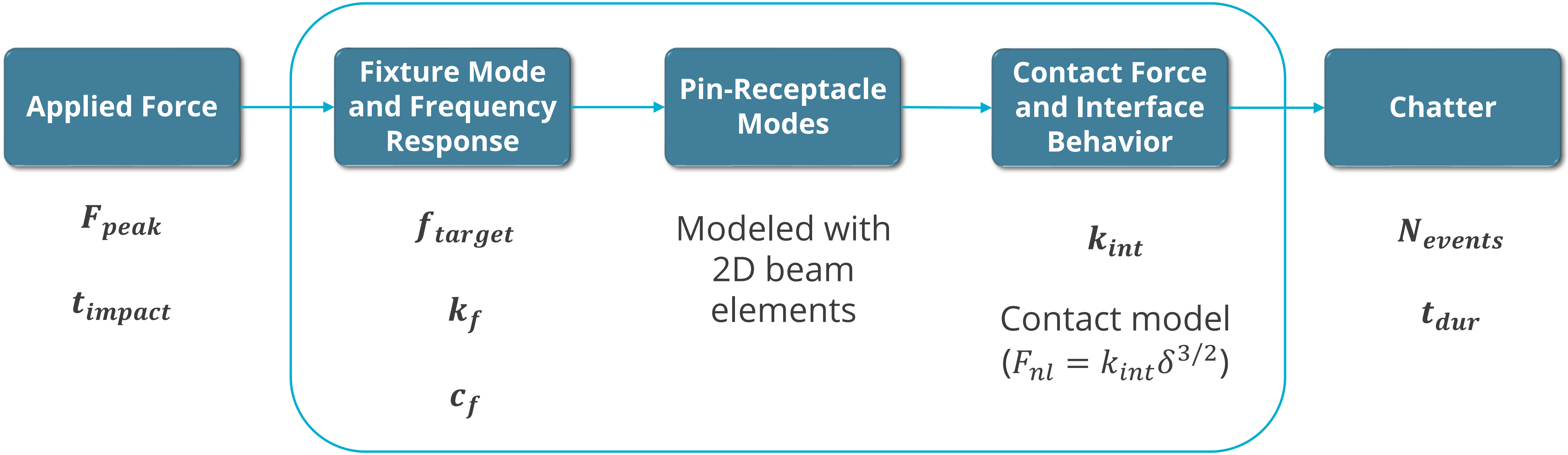


Hertzian contact idealizes complex microscale interactions



2D Model predicts chatter events and is computationally efficient.

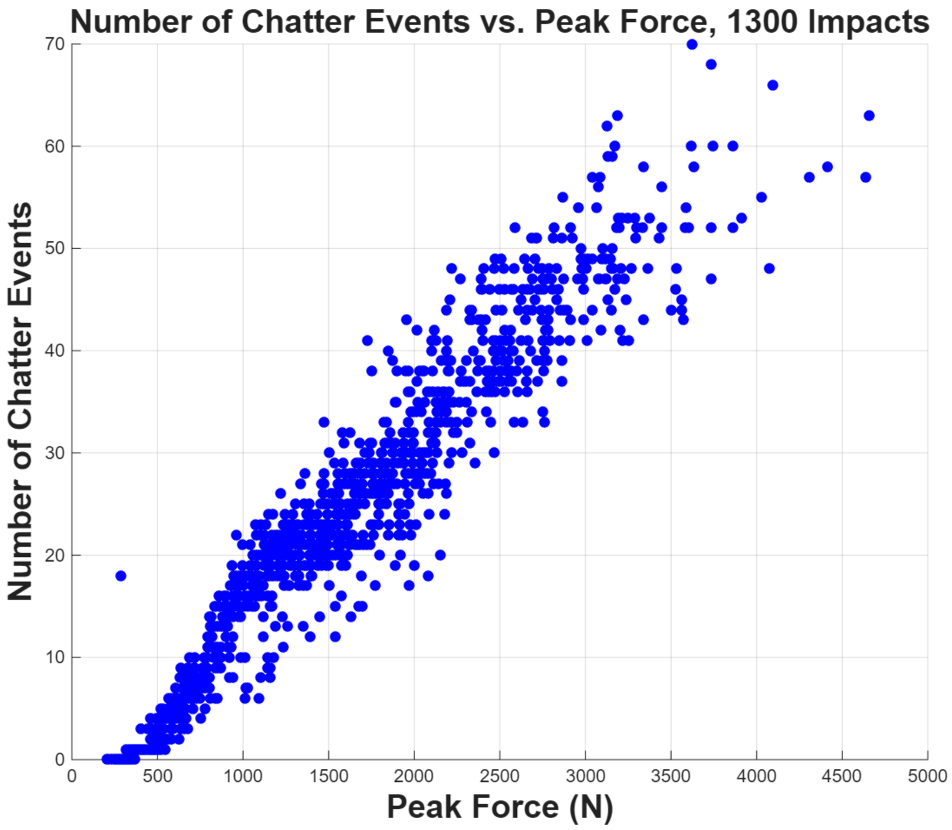
Modeling Methodology

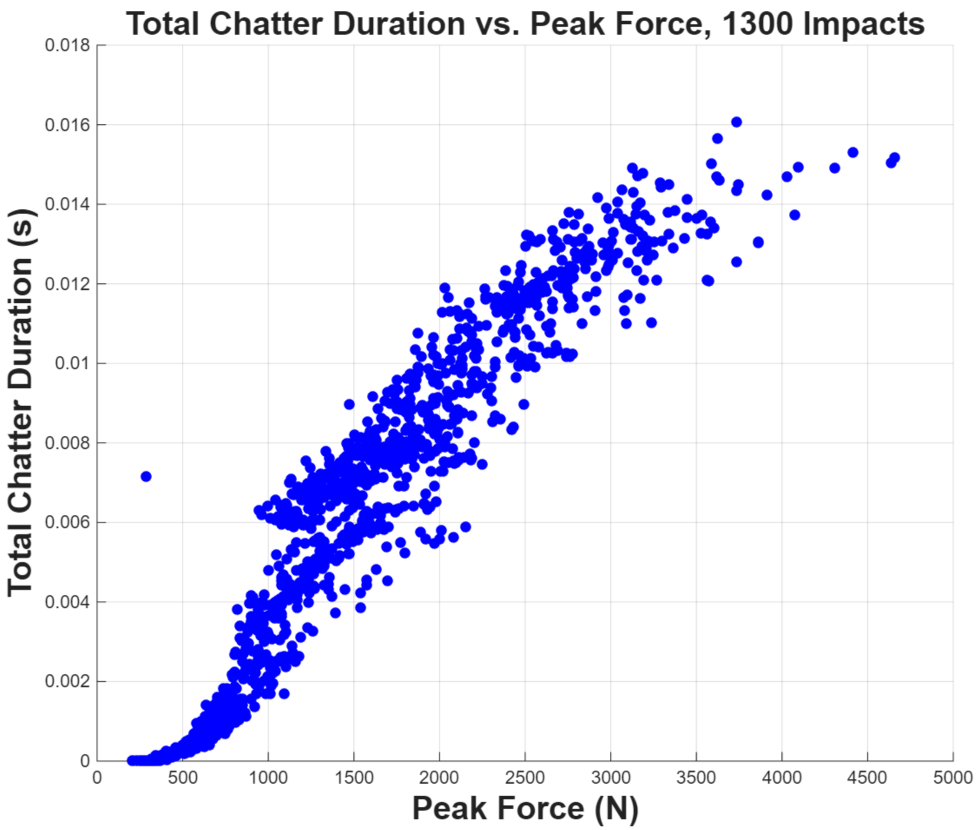


The 2D model represents the fixture, pin, receptacle, and the interface between them.

Experimental Results

Chatter Measurements in Oil

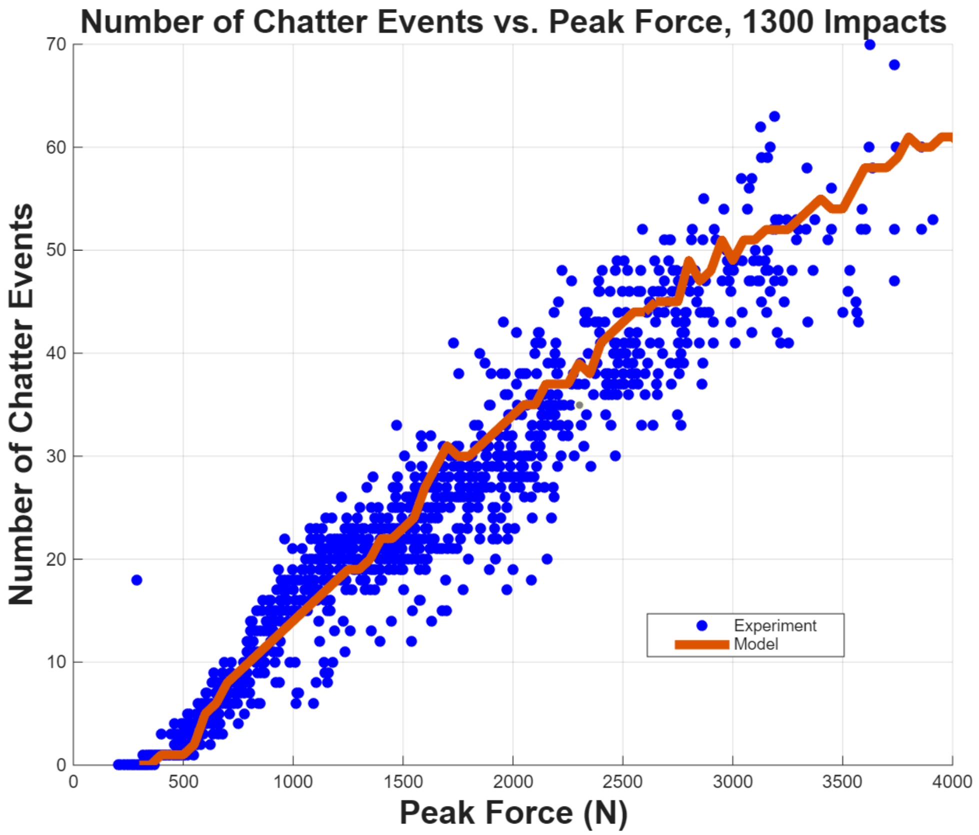


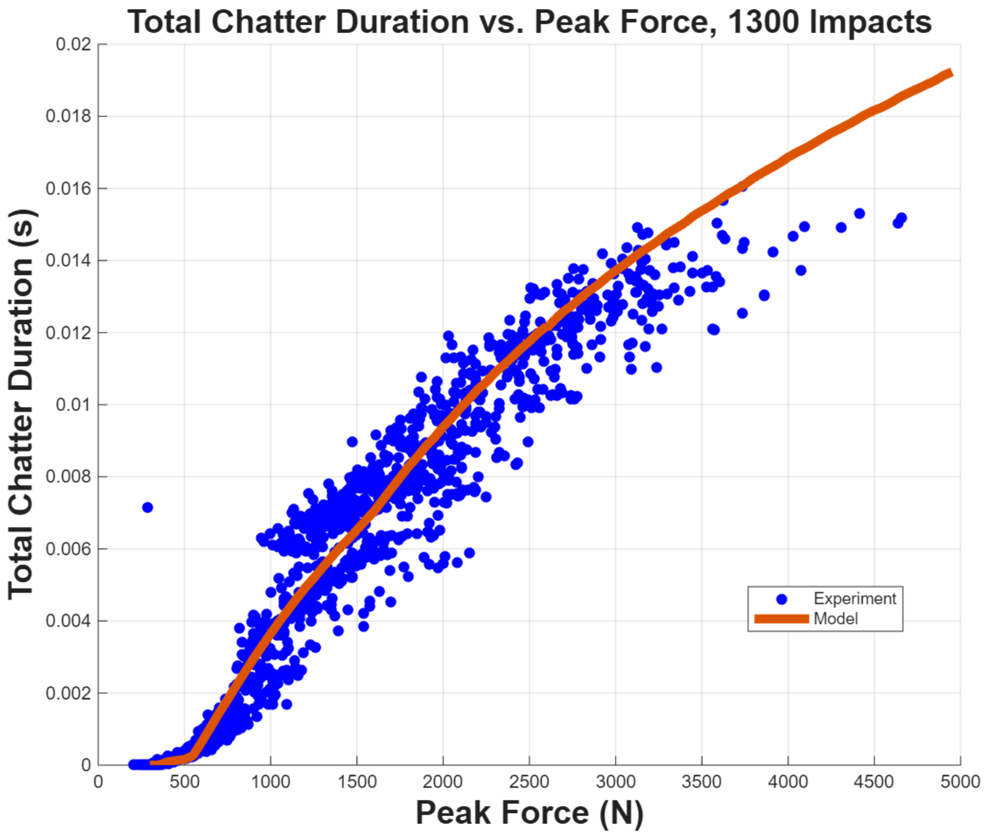


The number and total duration of chatter events are just two ways to quantify chatter characteristics.

Optimal 2D Oil Model Parameters and Results

Pulse Width t_{impact}	Fixture Target Frequency f_{target}	Fixture Stiffness k_f	Fixture Damping Ratio c_f	Interface Stiffness k_{int}
3.5e-4 s	1,521 Hz	110,406 N/mm	0.008	7,000 N/mm





The 2D model can be tuned to accurately predict chatter duration and number of events.

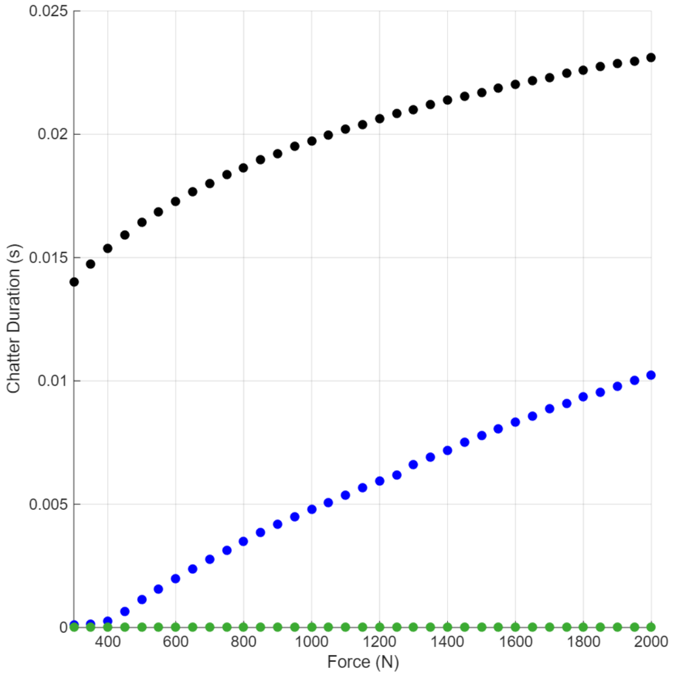
Parameter Studies

	Fixture Stiffness ↑ k_f	Interface Stiffness ↑ k_{int}	Target Frequency ↑ f_{target}	Fixture Damping ↑ c_f	Impact Amplitude ↑ F_{peak}	Impact Duration ↑ t_{impact}
Number of Chatter Events N_{events}	↓	↓	↓	↓	↑	↑
Chatter Duration t_{dur}	↓	↓	↓	↓	↑	↑
Chatter Threshold	↑	↑	↑	↑	N/A	↓
Chatter Distribution	Less bimodal	Less bimodal	Less bimodal	Less bimodal	More bimodal	More bimodal

Parameter studies were performed to understand how parameter affect chatter prediction.

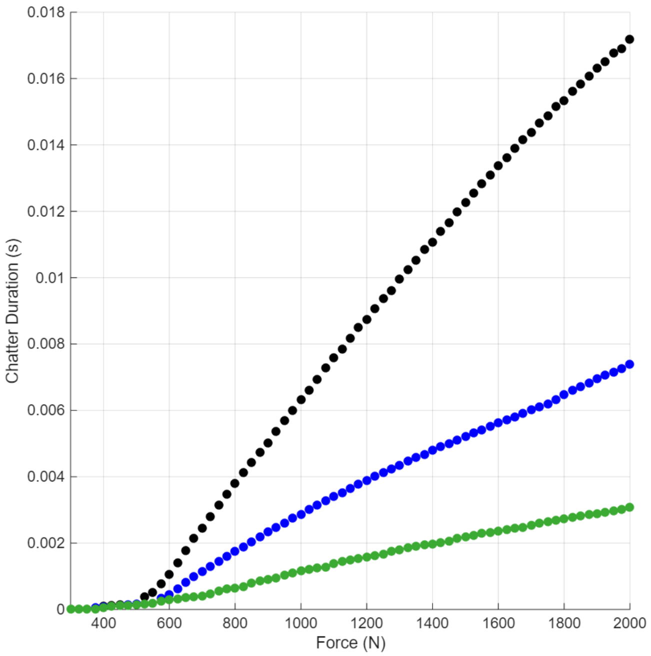
Most Influential Parameters

Interface Stiffness k_{int}



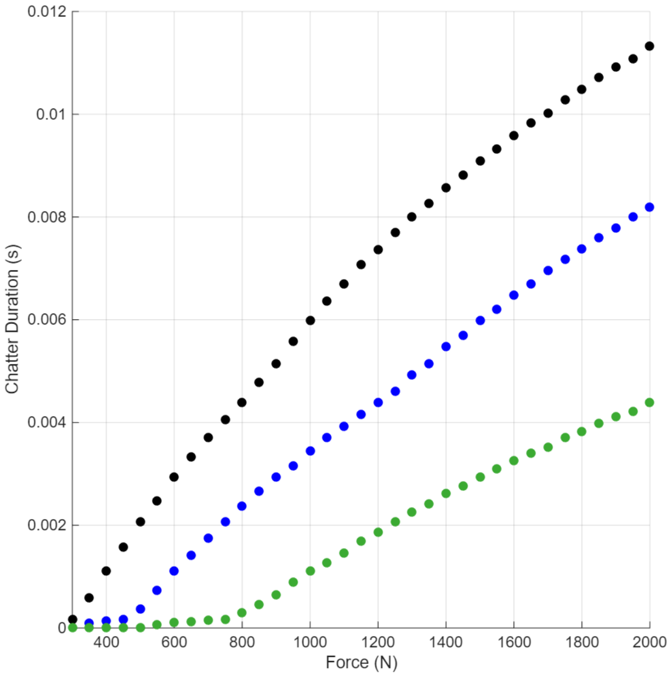
↓ Interface Stiffness k_{int}
↑ Chatter Duration t_{dur}

Fixture Damping c_f



↓ Fixture Damping c_f
↑ Slope

Fixture Stiffness k_f



↓ Fixture Stiffness k_f
↓ Force Threshold

These parameters have the most uncertainty and should be calibrated using experimental data.

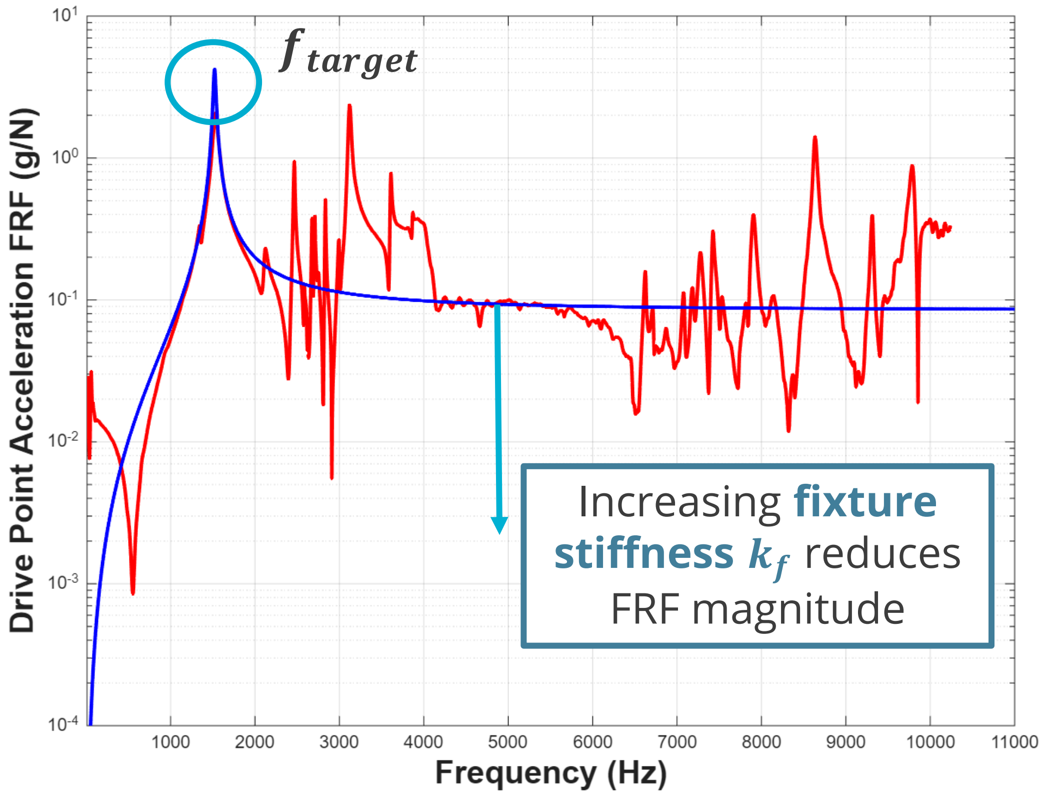
Fixture Parameter Calibration

Target frequency f_{target} is the natural frequency of the fixture's first bending mode

Select **fixture damping ratio c_f** to match peak width / height or use experimental value

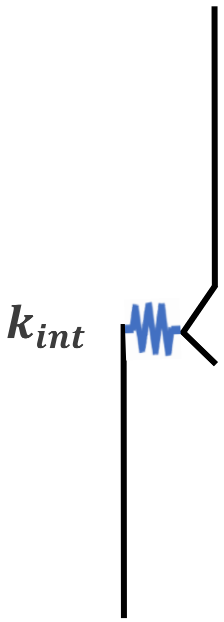
Change **fixture stiffness k_f** to shift the magnitude of the curve up or down

Comparison of experiment and model frequency response functions (FRFs)



Target frequency f_{target}, fixture stiffness k_f, and damping c_f are calibrated with a drive-point FRF.

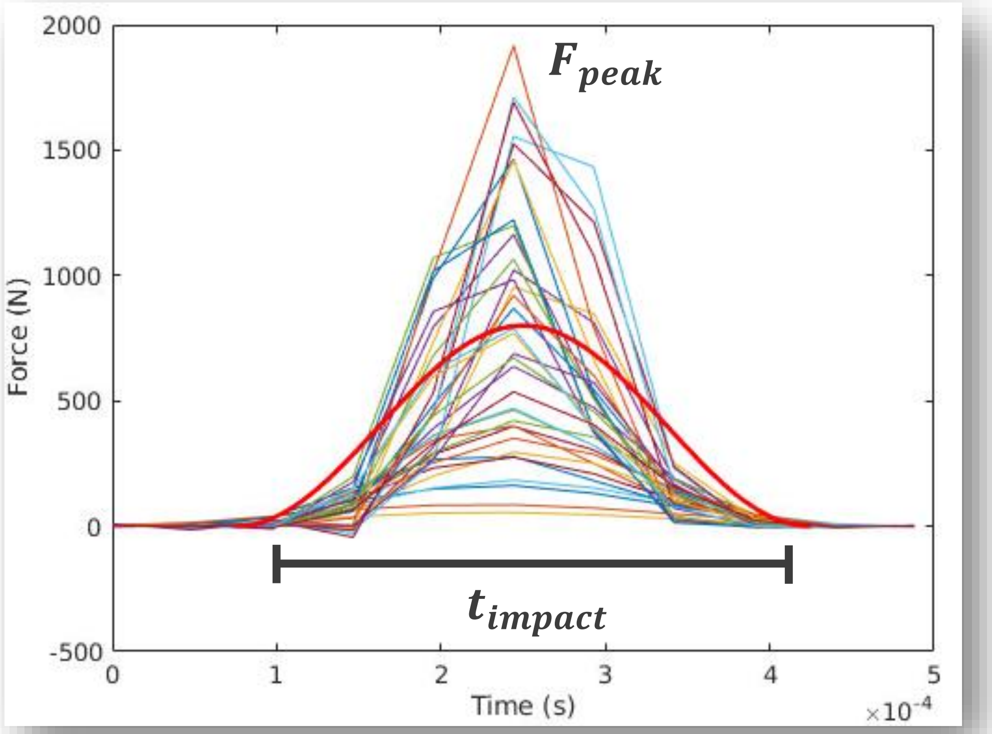
Selecting Interface Stiffness and Pulse Width



Interface stiffness k_{int} determines the contact force and **strongly affects chatter.**

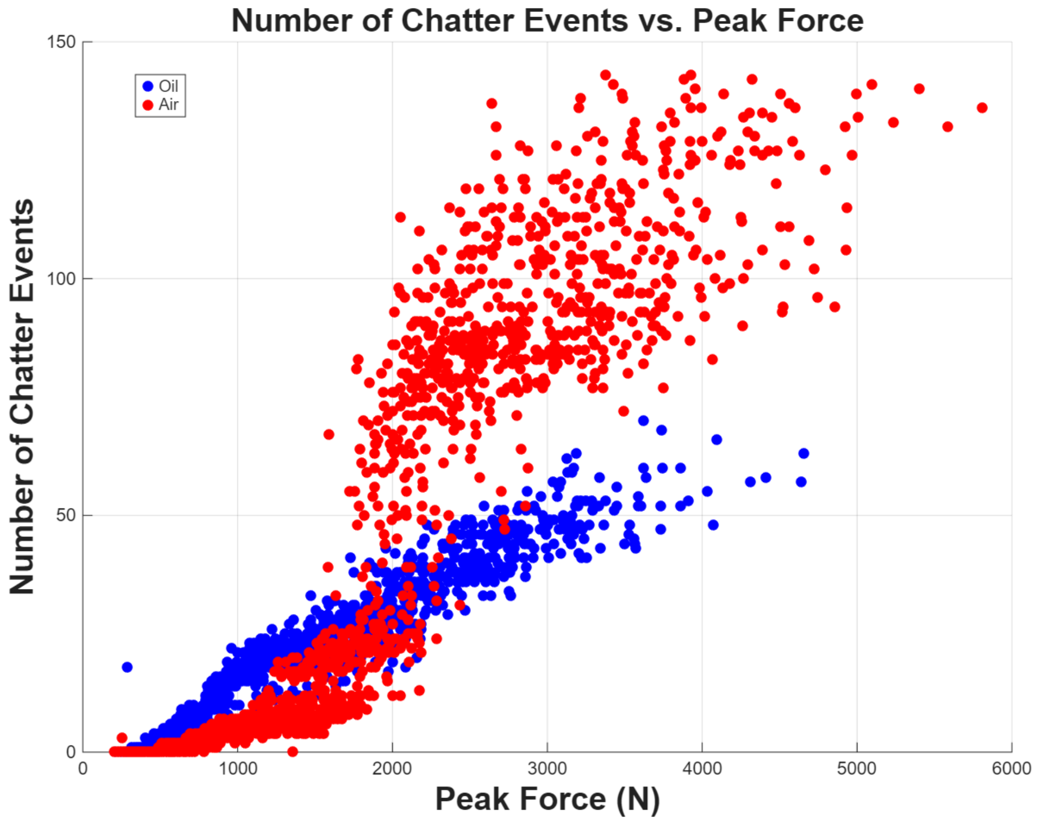
k_{int} cannot be directly measured experimentally. Instead, k_{int} was used to calibrate the model to match experimental chatter measurements.

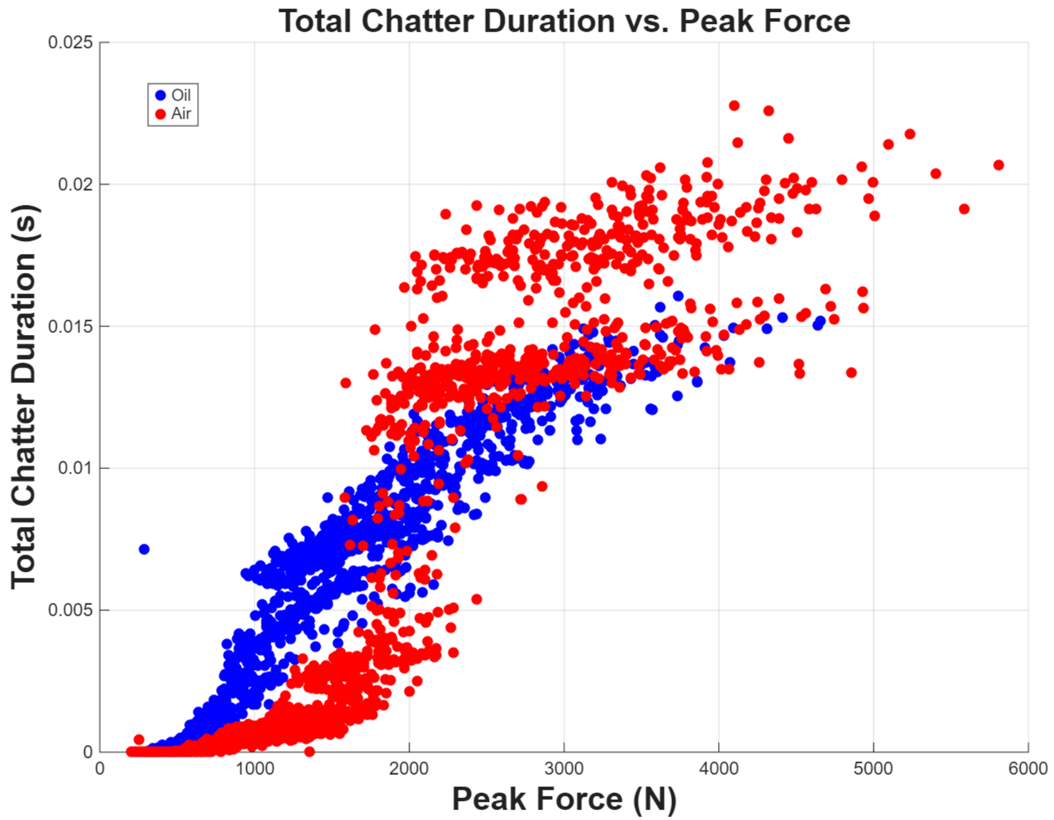
Experimental chatter data is needed to accurately select k_{int}.



Haversine pulse width t_{impact} was chosen based on the average experimental impulse duration.

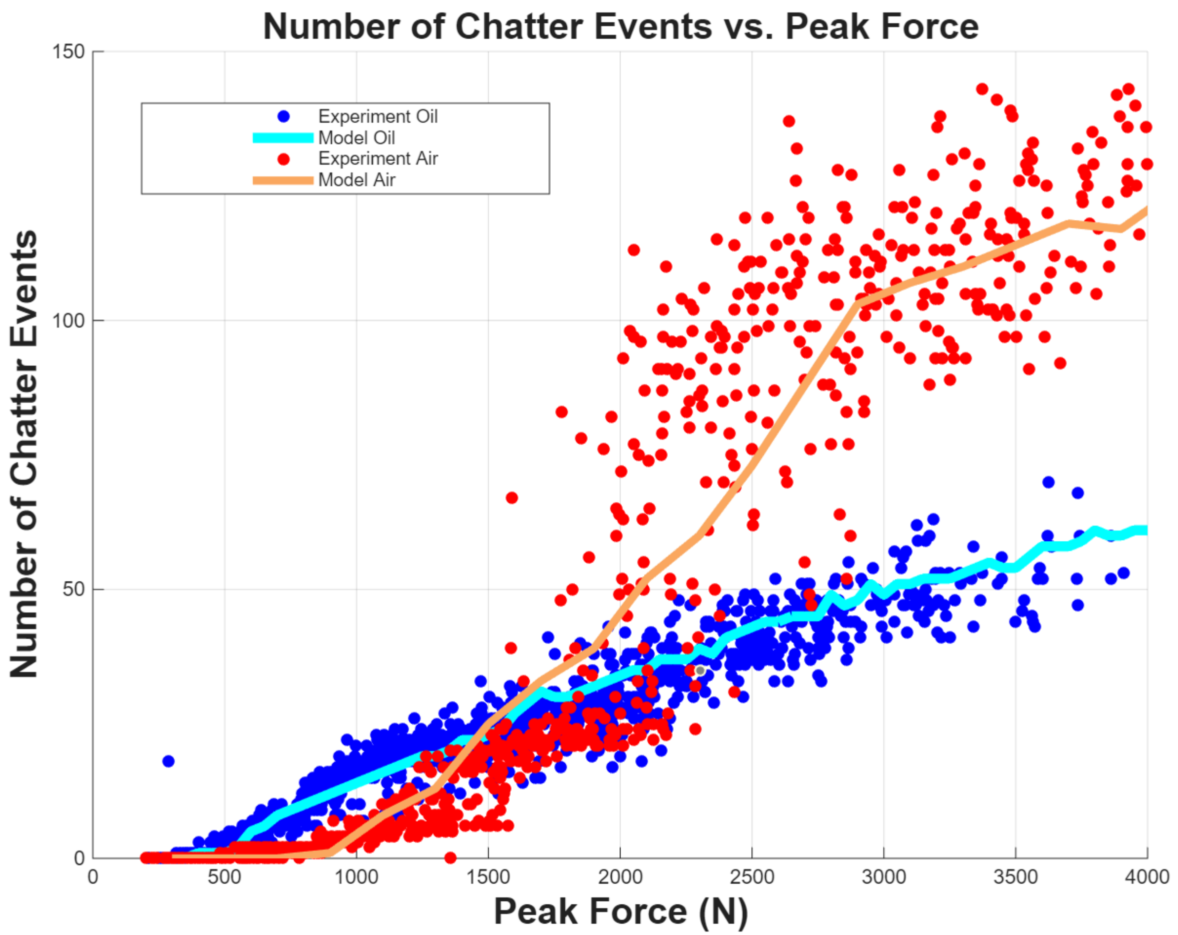
Oil vs. Air – Experimental Comparison





There is a significant difference in the observed chatter in air and oil.

Oil vs. Air – Model Comparison / Parameters



	Oil	Air
Fixture Stiffness k_f (N/mm)	110,406	110,406
Interface Stiffness k_{int} (N/mm)	7,000	14,500
Target Frequency f_{target} (Hz)	1521	1521
Fixture Damping Ratio c_f	0.008	0.005
Pulse Width t_{impact} (s)	3.5e-4	3.5e-4

The 2D model successfully captures chatter in oil and air with different parameters.

Oil may change the interface stiffness, but some of this effect may be caused by differences in the two test units.

Conclusions

- We observed different chatter characteristics between oil and air.
- Electrical chatter in oil (and air) can be successfully modeled by using a 2D FEM.
- This work demonstrates that the 2D model includes several key parameters that enable the model to be calibrated using experimental data and to provide accurate chatter predictions.
  - Drive Point FRF was used to calibrate fixture parameters k_f, f_{target}, c_f at impact location.
  - Chatter measurements at different force amplitudes were used to calibrate the interface stiffness k_{int}.
  - 2D beam elements accurately model the dynamics of the contact pair.

Chatter in oil and air can be accurately represented by using the same 2D model with different parameters.

Future Work

- Study the repeatability of this research by replicating portions of this research.
- Investigate other contact interface models.
- Explore other methods for modeling damping (Rayleigh, viscoelastic, robust fluid-structural interaction).
- Expand chatter research to different contact pair designs.

Acknowledgements

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Questions?