Collaborations through REUs – A Lehigh Facility User Experience

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Research Group, Spring 2023

UNIVERSITY OF SOUTH CAROLINA

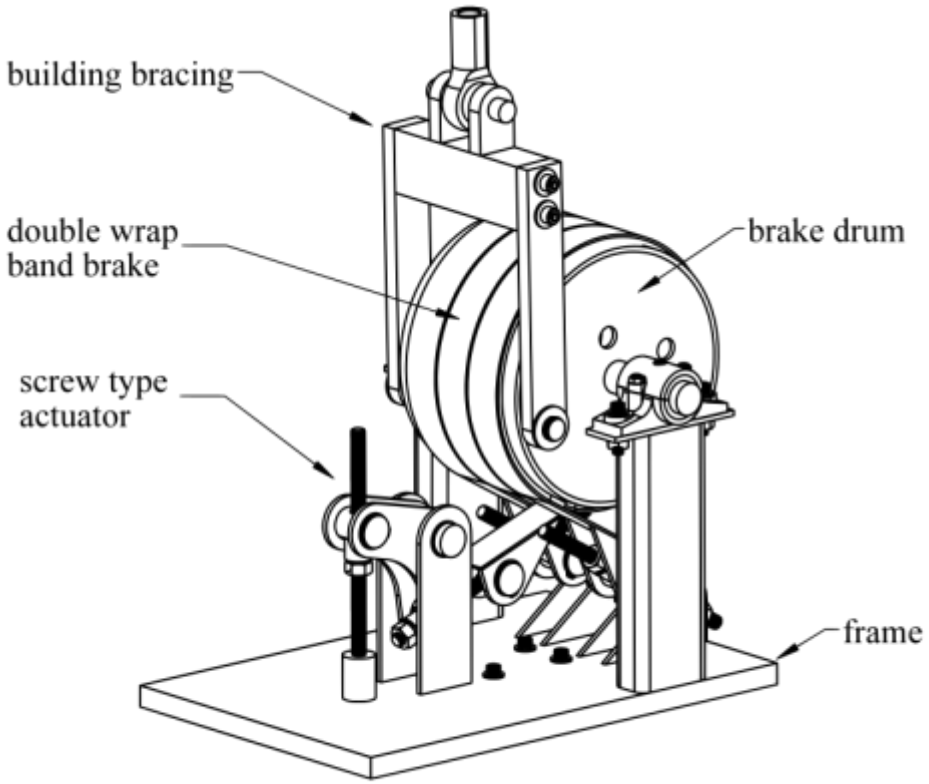
Undergraduate Research

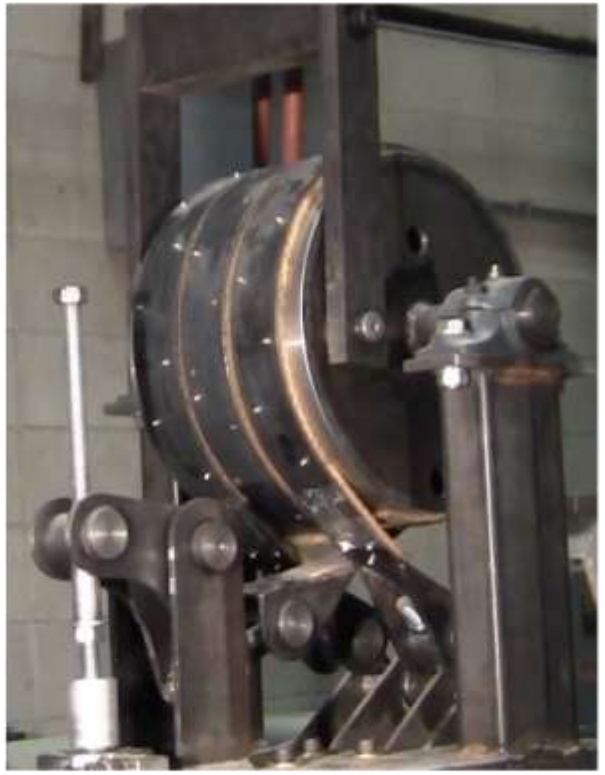
The lab has a large group of undergraduates doing active research. Currently about 25 undergraduate students.

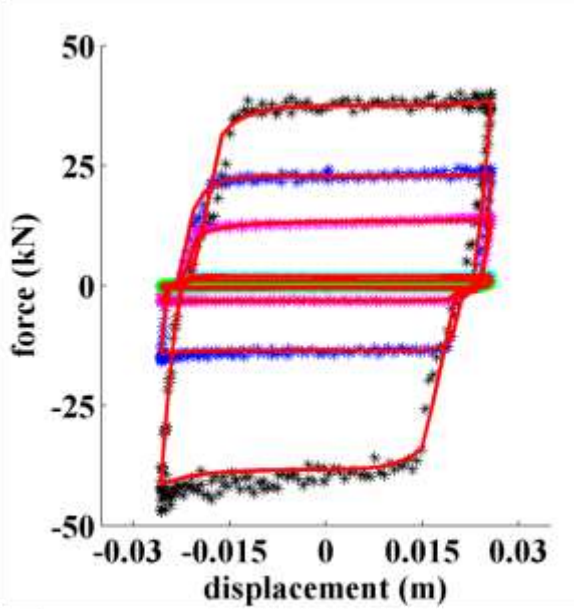
Undergraduate

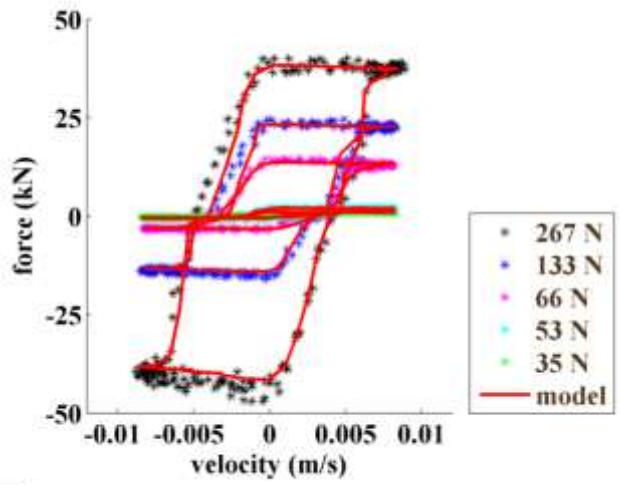
University of South Carolina

Banded Rotary Friction Device (BRFD)



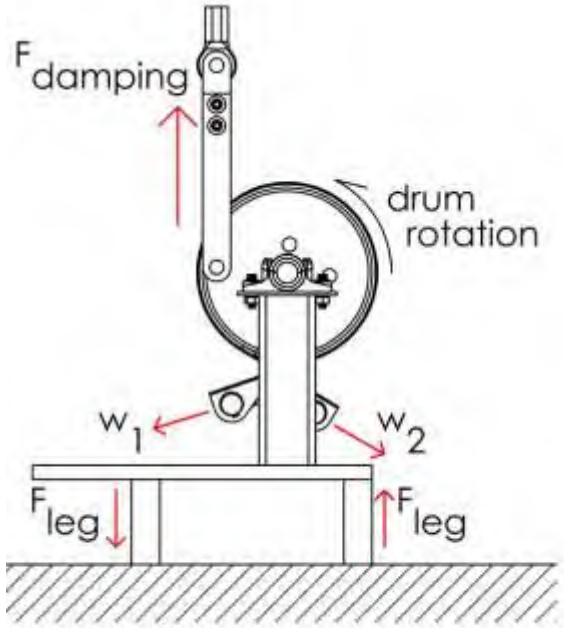


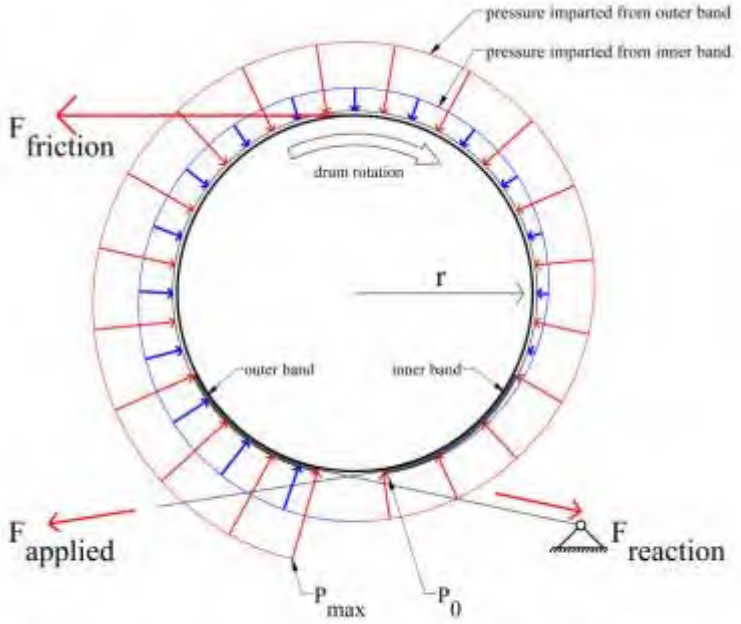


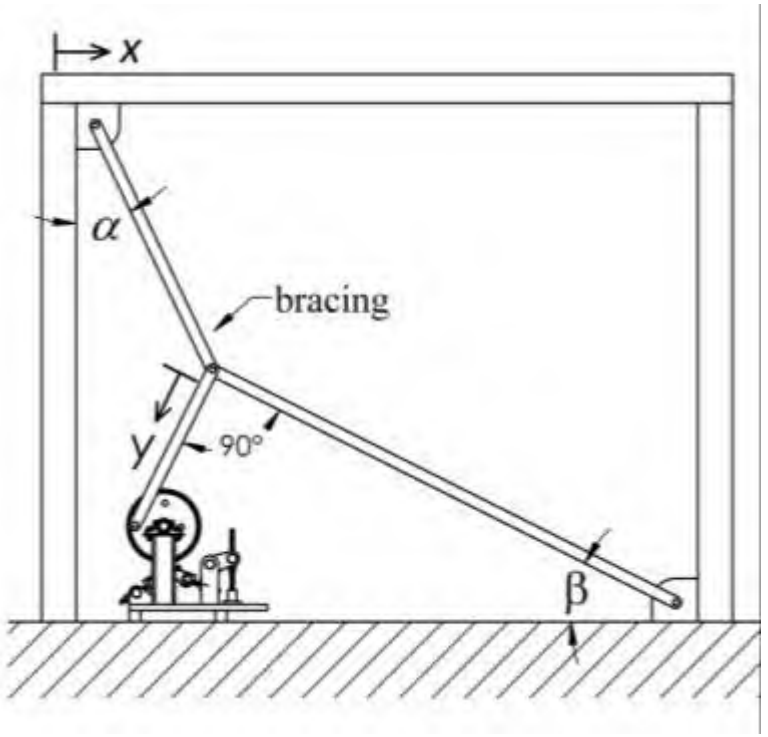


mechanical advantage of 142

Banded Rotary Friction Device (BRFD)







$$F_{\text{reaction}}/F_{\text{applied}} = e^{\mu\phi}$$

$$F_{\text{applied}} = \frac{F_{\text{friction}}}{(e^{\mu\phi} - 1)}$$

$$F_{\text{damping}} = \frac{T}{r_b} = \frac{F_{\text{friction}} \cdot r}{r_b}$$

BRFD Timeline

The BRFD was:

- Built in my home shop in 2014
- Journal paper published in 2015
- Iowa State Shop Manager pressed us to trash it in Fall 2017; Jim Ricles asked us to ship it Lehigh.

Iowa State lab manager happy to see it go!

brake

Wood, Douglas L [CCE E] <dwoody@iastate.edu> Thu, Feb 8, 2018, 9:20 AM

to Austin

Austin
I am putting the friction brake on a pallet today in order to have it shipped out. Would like to know what all needs to go with this thing. See me when you have a chance.
Thanks

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IOWA STATE UNIVERSITY

BRFD in 2019 with new bands

BRFD Further Developed over three summers

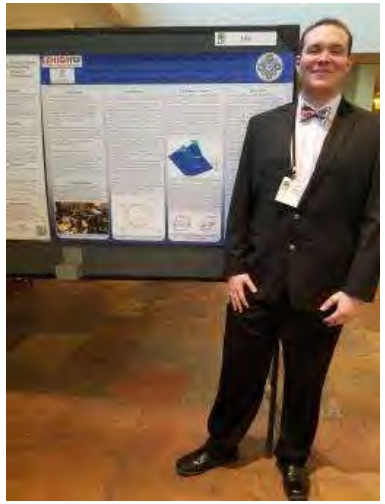
REU students participating in summer REUs have continued the project since 2019

Mitchell Stiles
2019

COVID-19
2020

Daniel Coble
2021

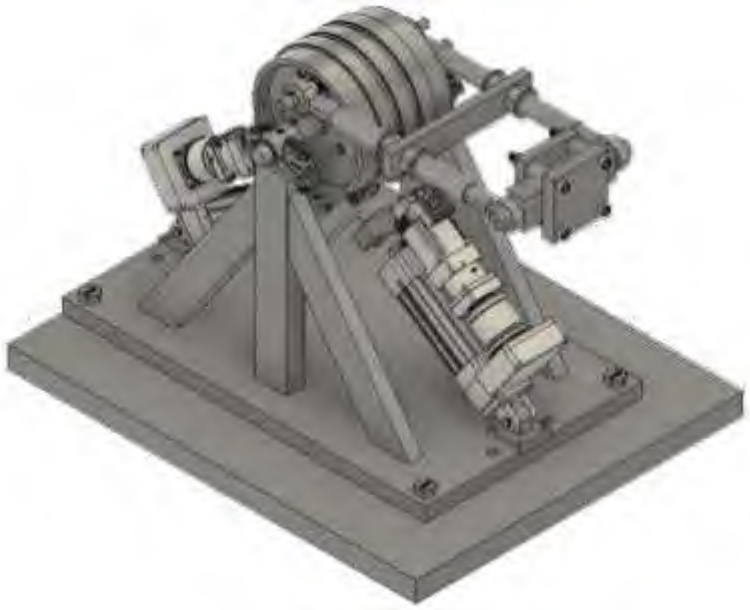
Parker Huggins
2022

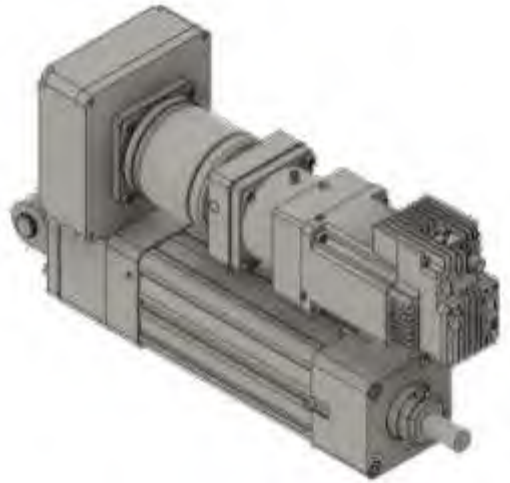


Mitchell Stiles – System Hardware Improvement

Expanding to Semi-active Device

New device is being engineered to create a stiffer design and incorporate electric actuators to create a semi-actively controlled friction damping device.

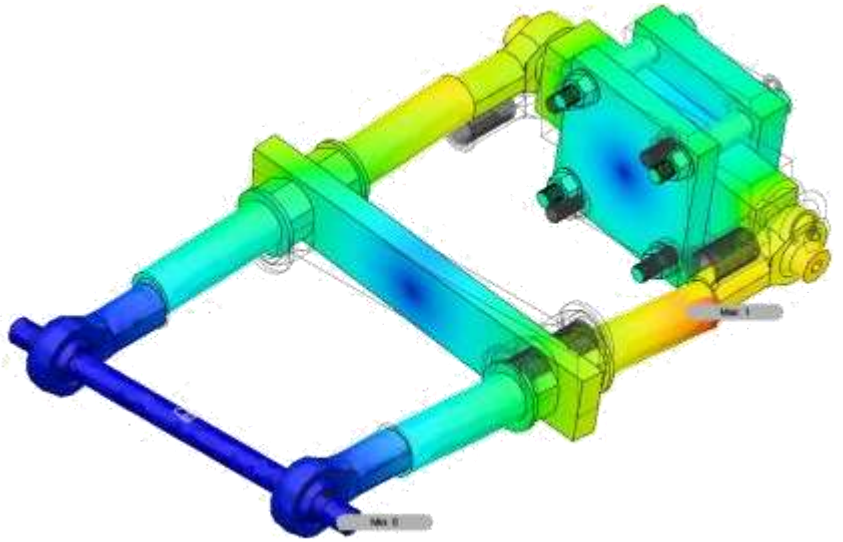




Rendering new Design

New Structure to Drum Connection

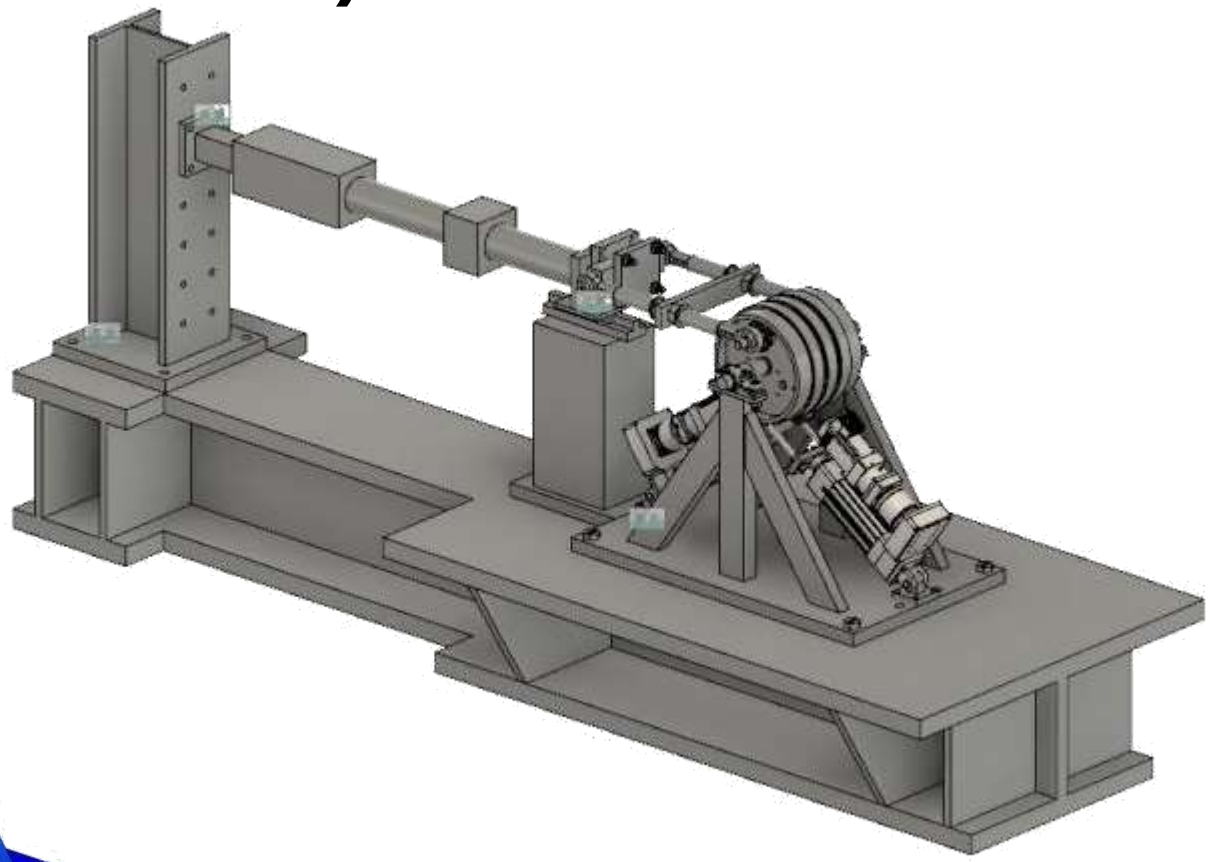
Old drum with previous connection



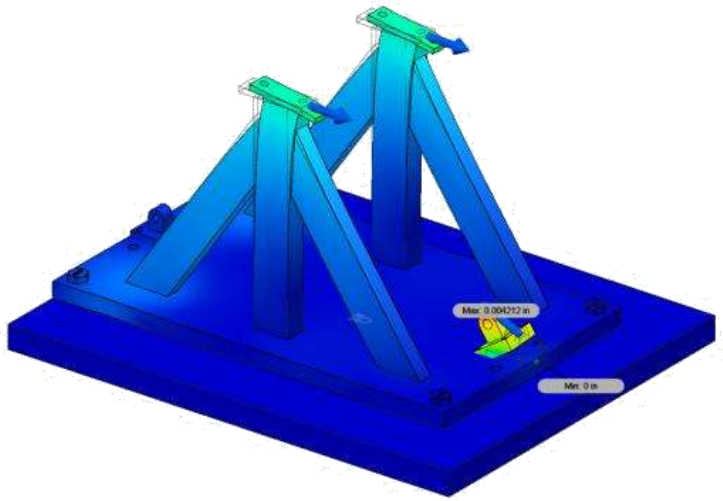
Mode Number	Frequency (Hz)
1	60.64
2	71.9
3	275.6
4	285.6
5	367.6

Methodology (Drawings and Simulation)

New steel drum



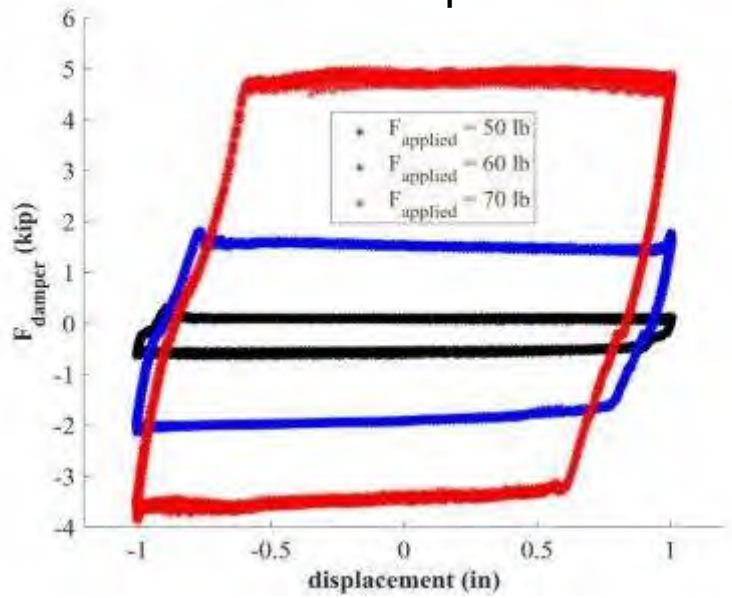
I-Beam Foundation with semi-active BRFD



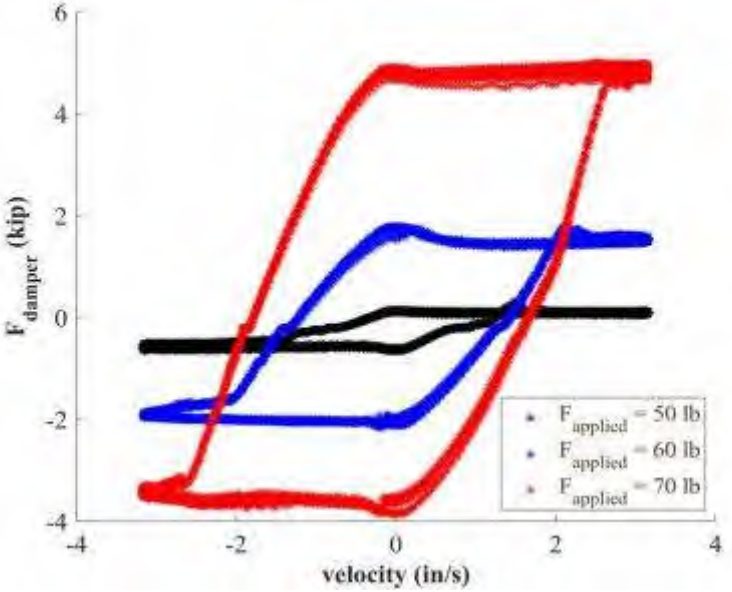
simulation is of the new frame and support struts

Preliminary Results

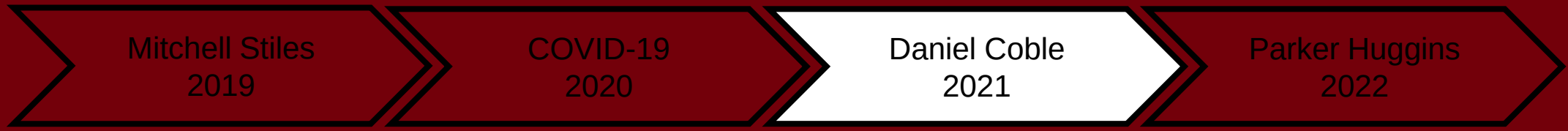
Force vs. displacement



Force vs. velocity

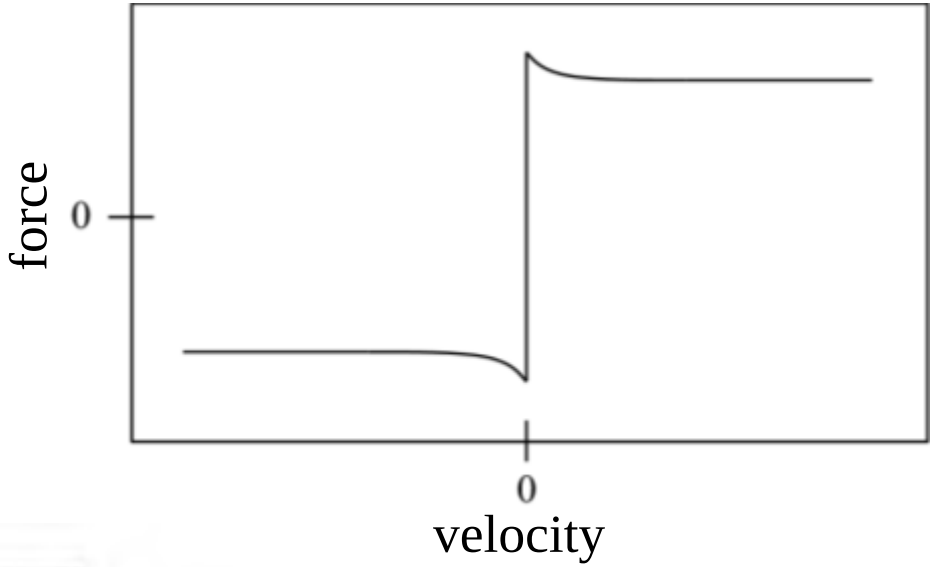


Daniel Coble – Friction Modeling using Physics Informed Machine Learning



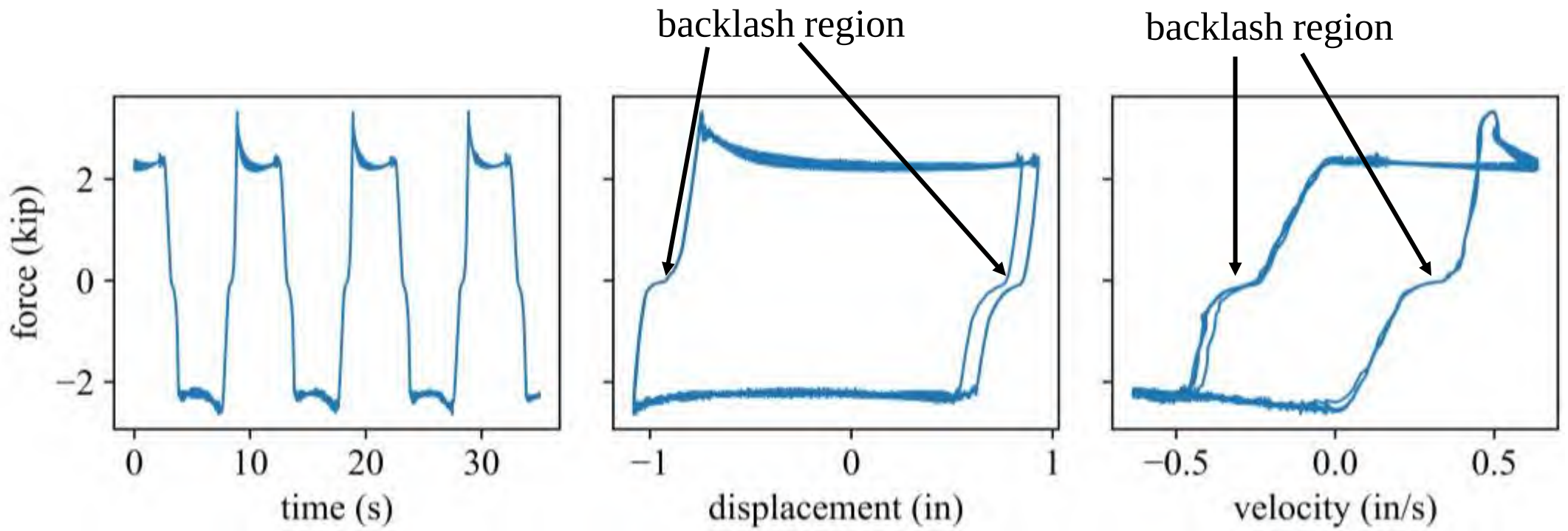
Problems in modeling friction

- Rate-dependent properties.
- Hysteretic behavior.
- Stribeck effect: static friction is greater than kinetic friction.
- Backlash: loss of friction during reversal of travel.



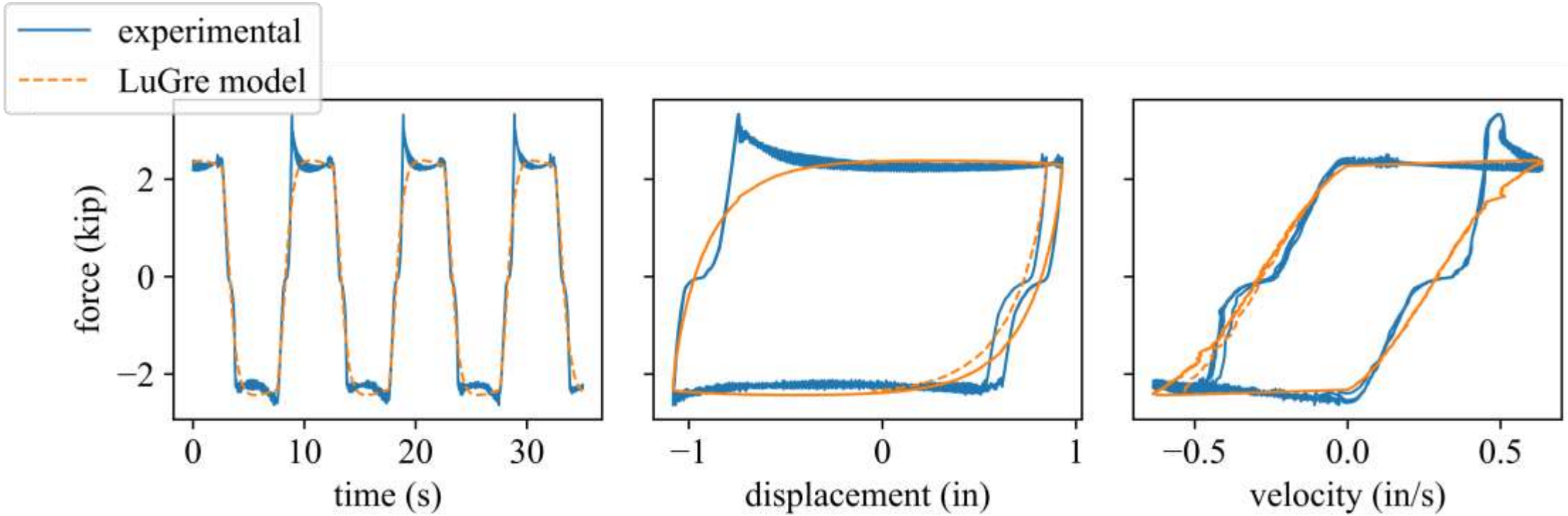
Device Characterization

- The device was characterized with four sinusoidal displacement tests with frequencies between 0.1 Hz and 1.0 Hz.
- The backlash effect: self-energizing effect depletes during reversal of travel.



Problems using current models

- Standard dry friction models like the LuGre model cannot capture backlash.



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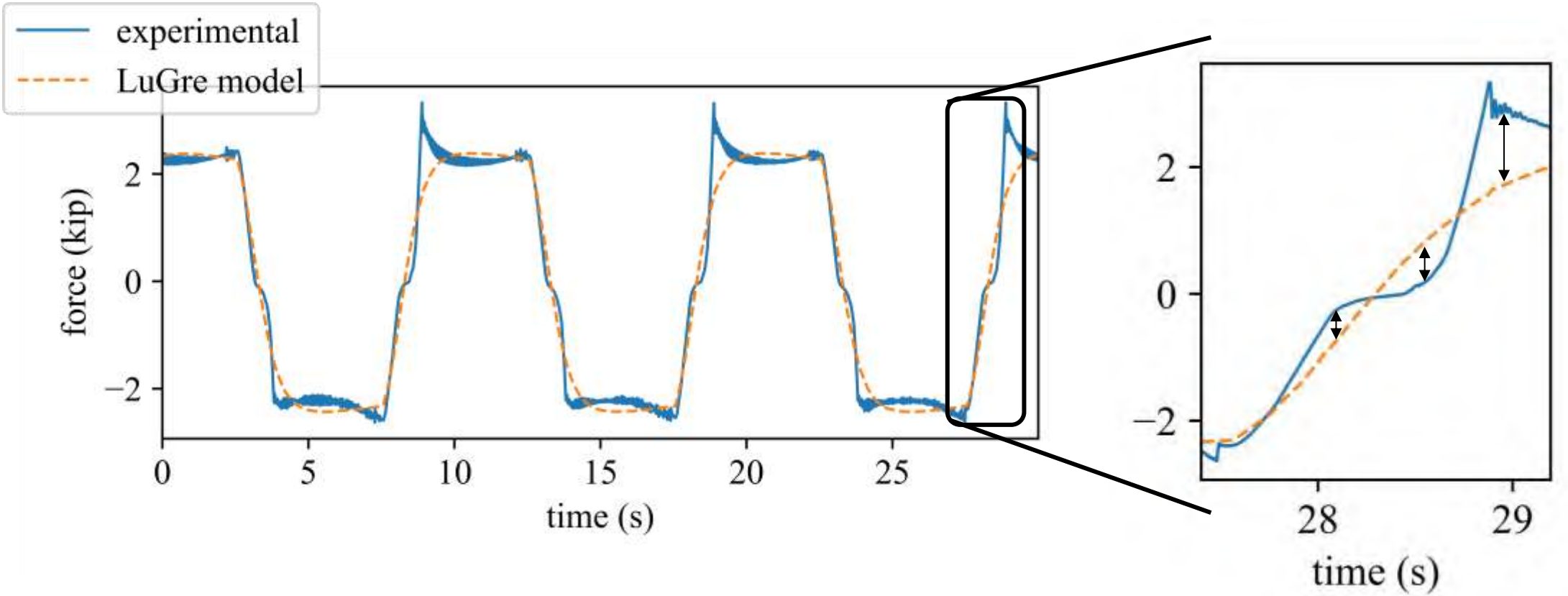


Model Development

- Physics-informed component: the LuGre model.
- A ‘rate and state’ model with one state variable commonly used to describe dry friction systems.
- Physical interpretation of parameters:
  - Static parameters: , , .
  - Dynamic parameters: , , .
- controls hysteresis rate of change–backlash effect.

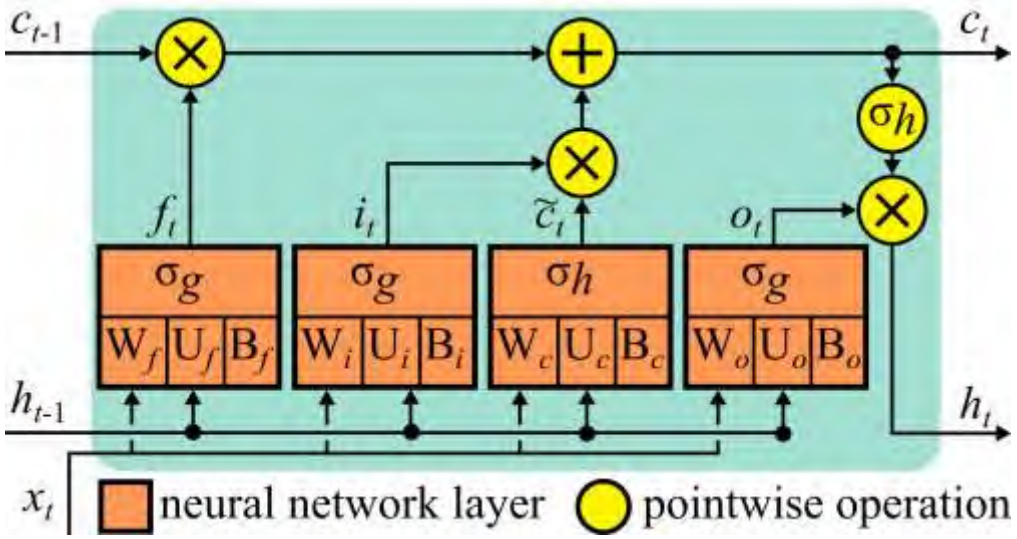
$$\dot{z} = v - \sigma_0 \frac{|v|}{g(v)} z$$

$$F = \sigma_0 z + \sigma_1 \dot{z} + \sigma_2 v$$

$$g(v) = F_c + (F_s - F_c)^{\left(\frac{v}{v_s}\right)}$$

Model Development

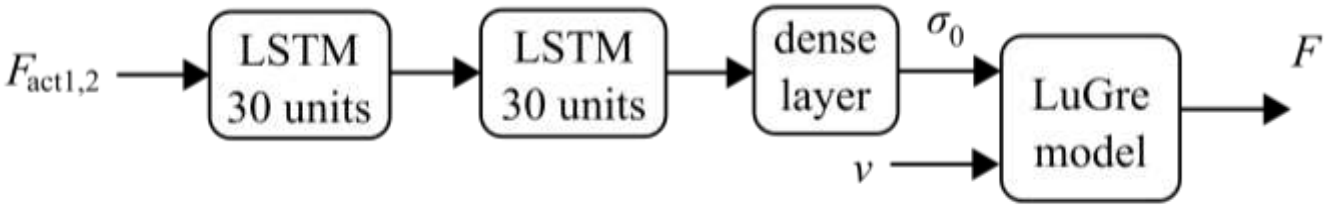
- Machine-learning component: Long short-term memory.
- A class of recurrent neural network designed to detect longer time-series patterns than standard RNNs.
- State vectors and maintain state information.



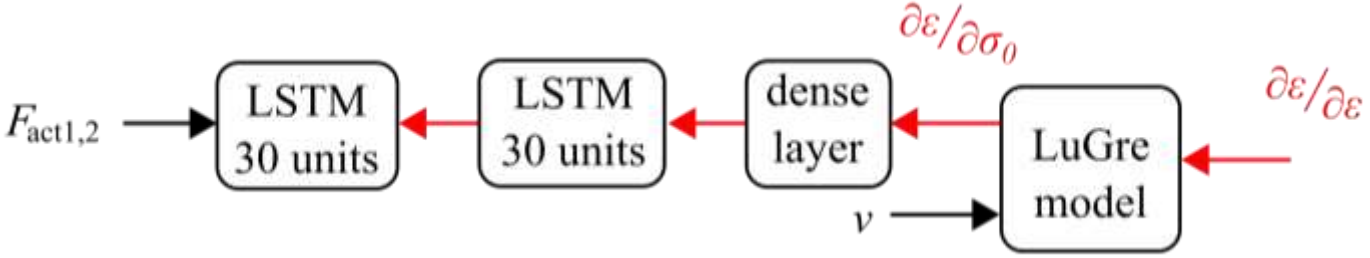
Model Training

- Static parameters , , and found with a least-squares analysis.
- Supervised training procedure using damping force measured during characterization test.
- Backpropagation provides an error gradient as an intermediate value in updating weights.

Forward inference

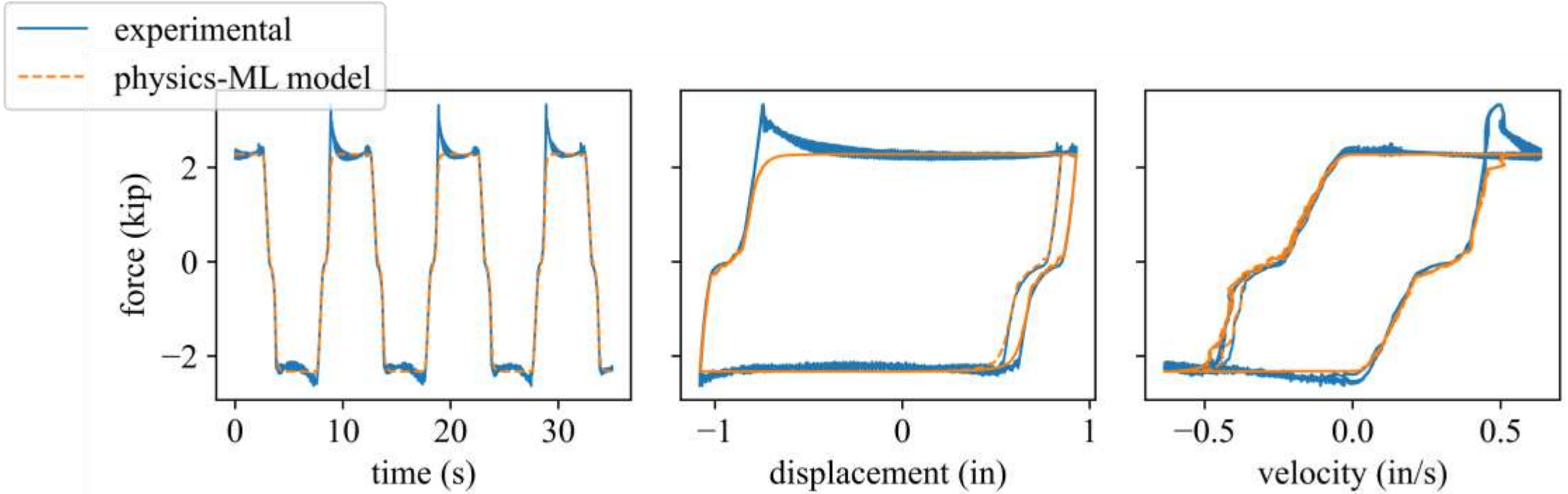


Backpropagation



Results

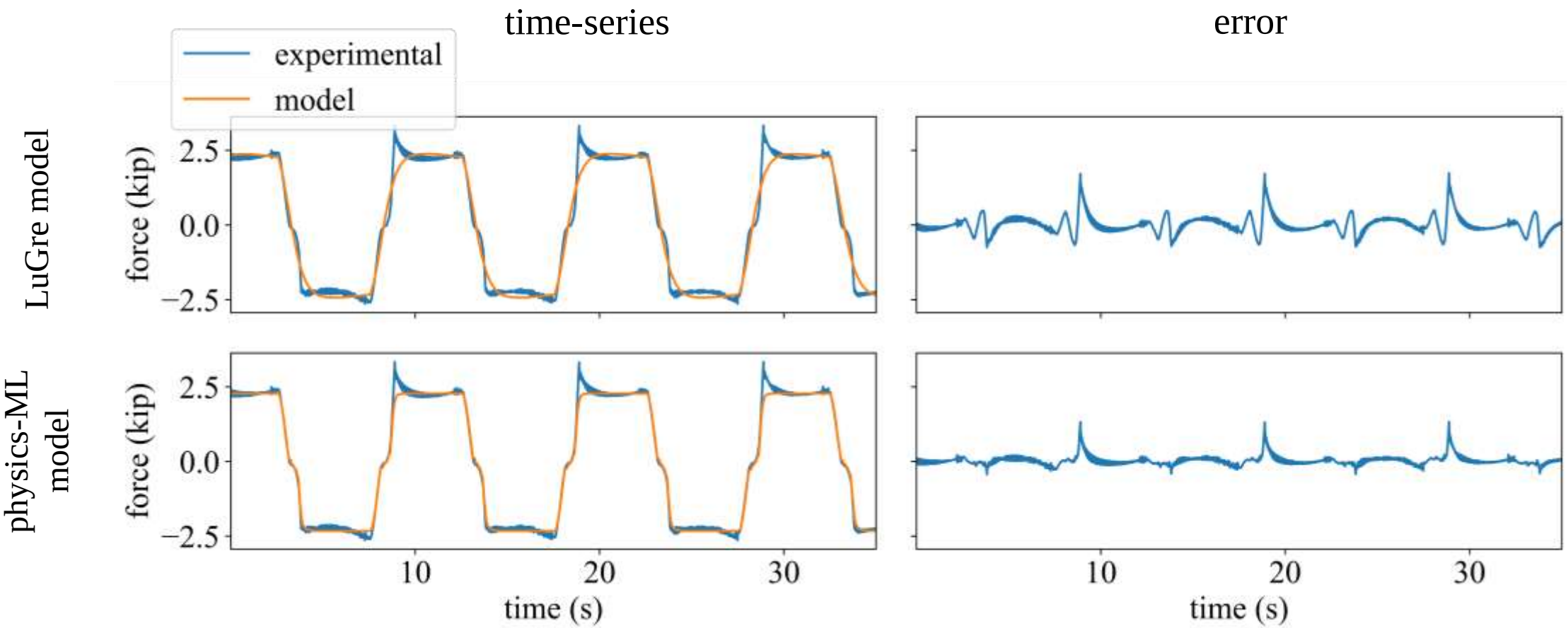
- Compared against LuGre models found with least-squares fit.
- Normalized root mean squared error from 6.71% to 3.16%, a reduction of 53%.
- Most of the error reduction comes from the ability to reproduce the backlash effect.



South Carolina

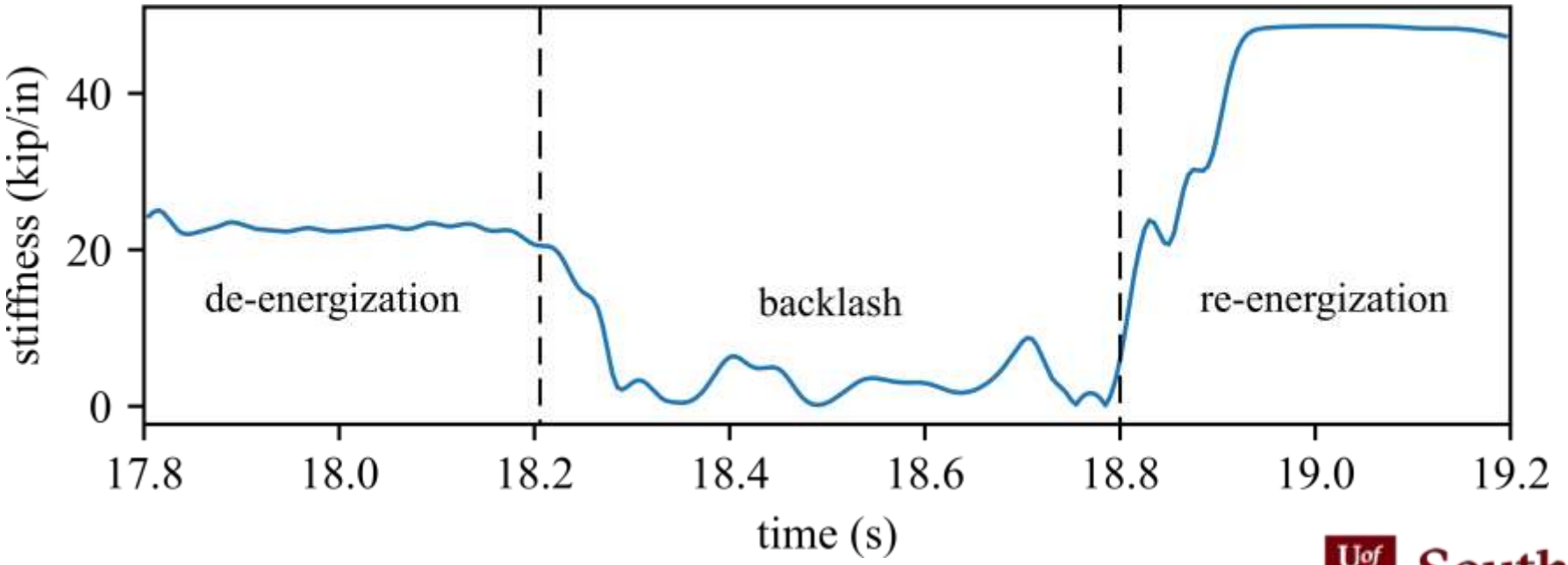
Results

Comparison between standard LuGre model and physics-ML model



Results

- The ML model produced a time-dependent function for —without any measurement of .
- Applications in ‘indirect measurement’ time-series characterization of physical systems.



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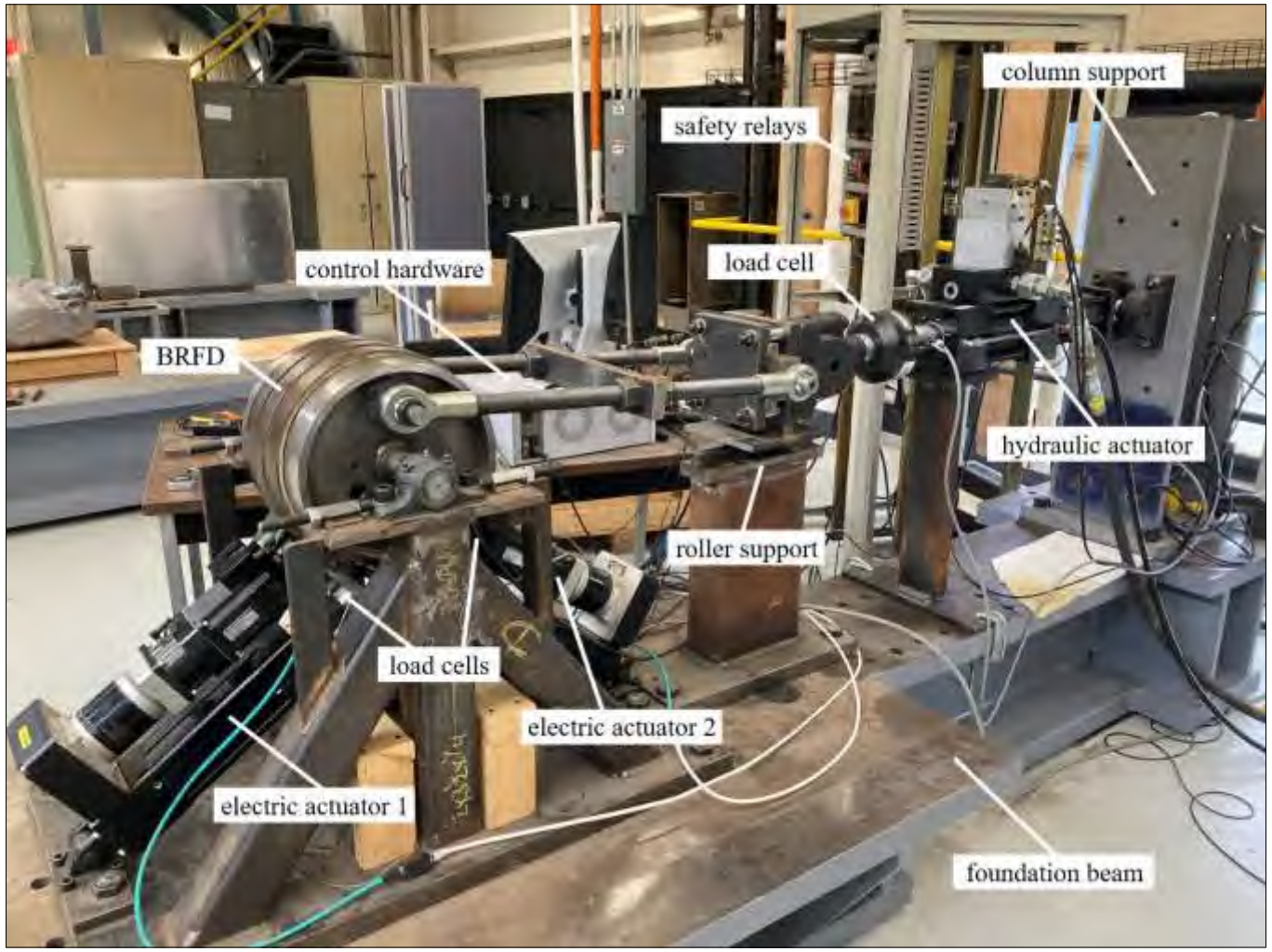
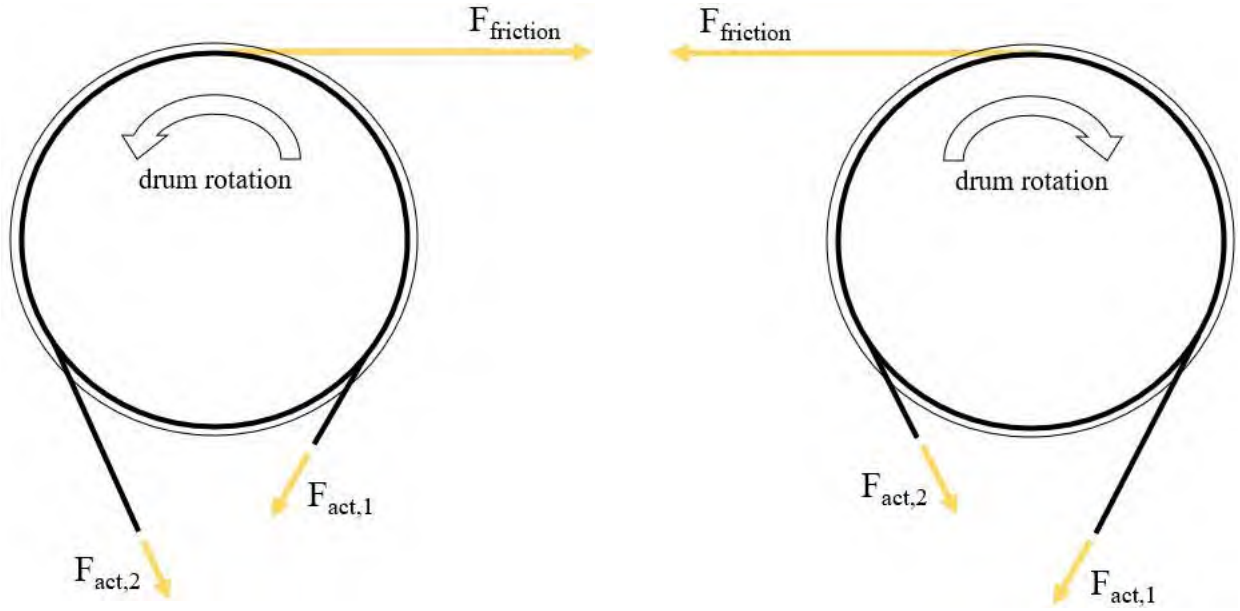
Parker Huggins – Characterization of a Semi-active Model

Test Setup


column support
safety relays
control hardware
load cell
BRFD
hydraulic actuator
roller support
load cells
electric actuator 2
electric actuator 1
foundation beam

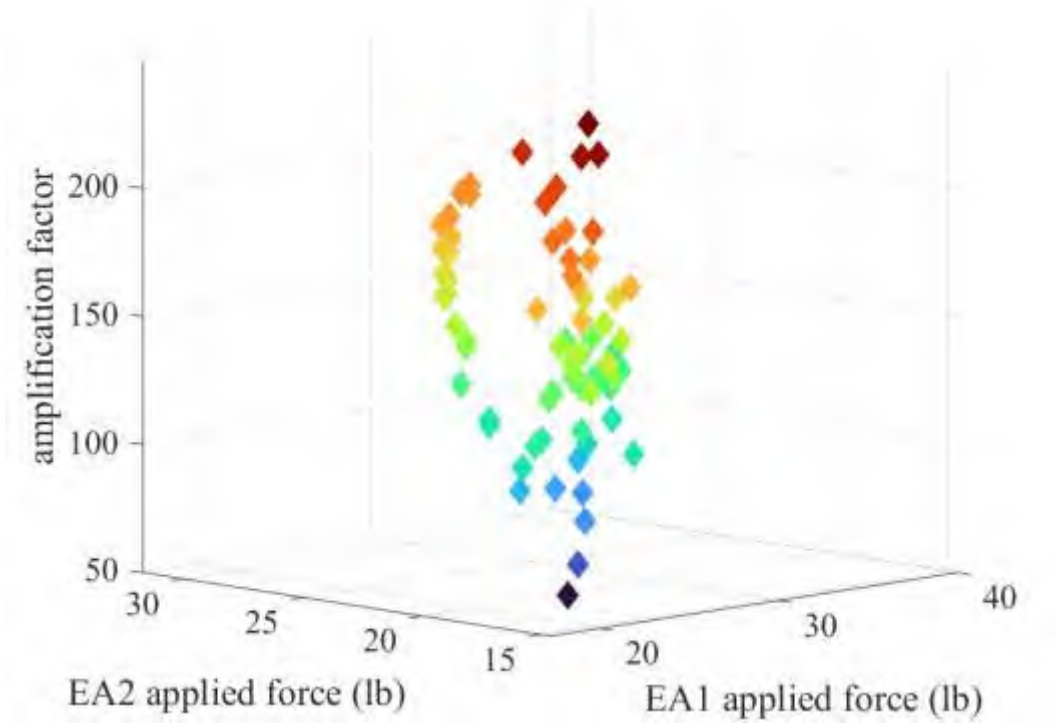
BRFD Modeling Difficulties



forward rotation **backward rotation**

- **Friction:** stiction, hysteresis, etc.
- **Deflections:** electric actuators/ friction bands
- **Sensitivity:** initial conditions

Damper Force Amplification



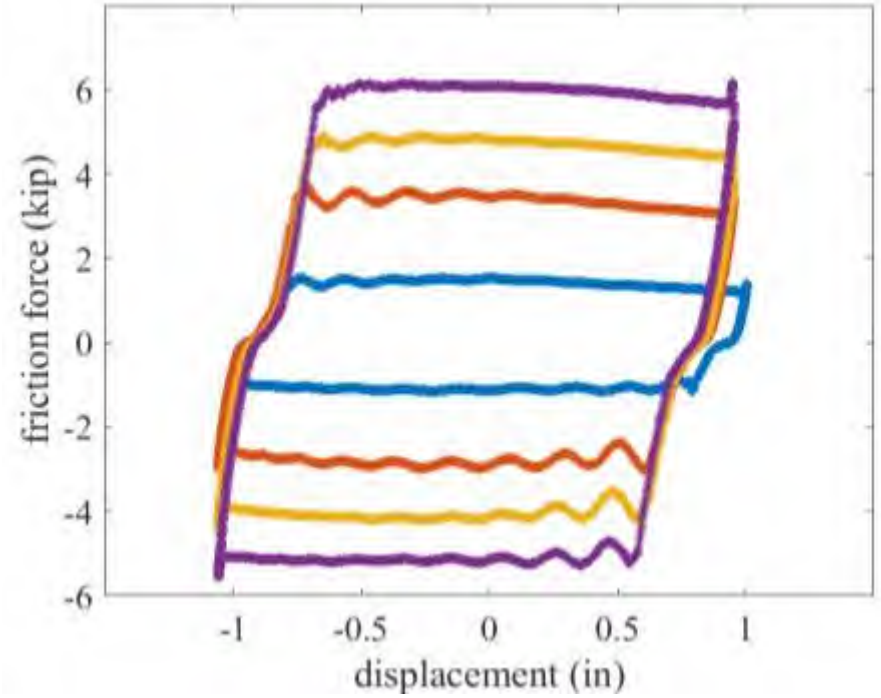
- Factor by which the BRFD amplifies its input
- Ratio of damping force to slack-actuator force

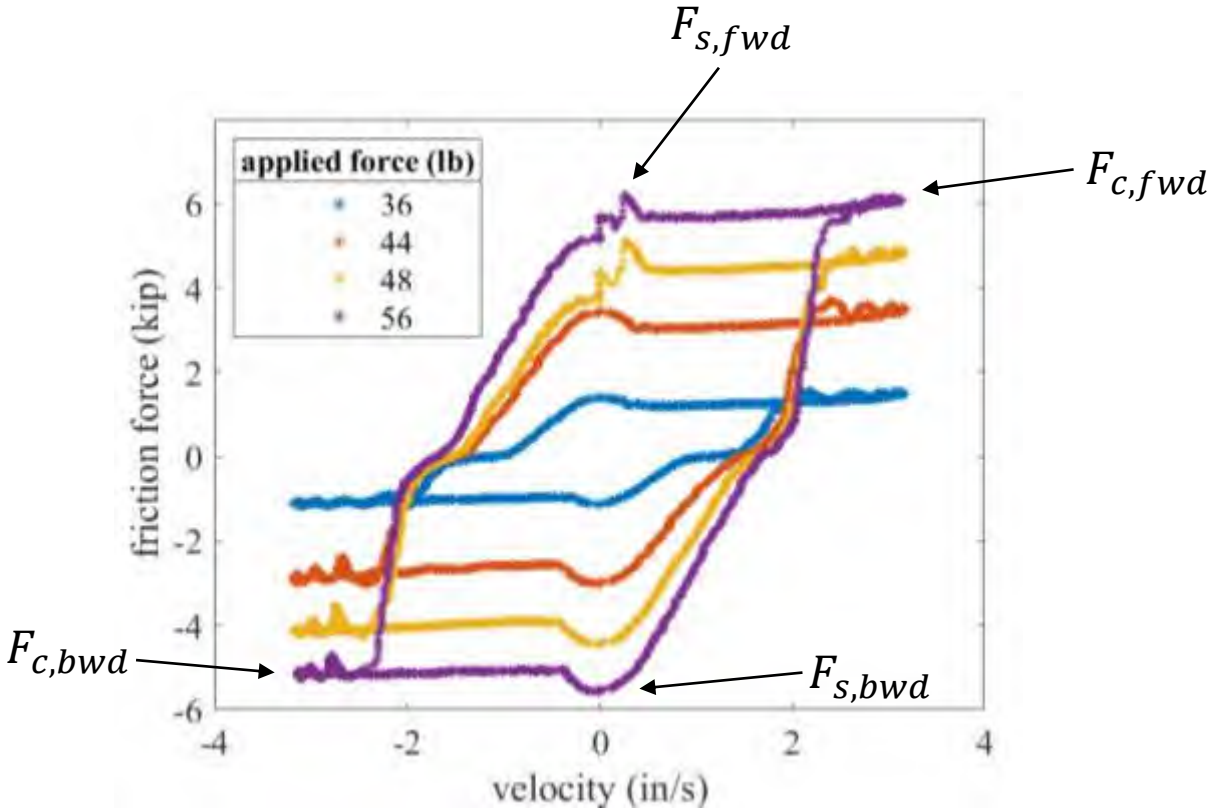
Forward rotation:

Backward rotation:

- BRFD capable of achieving amplification factors
- Amplification **increases** with pretension forces

Passive to Semi-active





Approach

- Sets of passive characterization tests conducted for analysis
- Used sinusoidal input with amplitude **1 in** and frequency **0.5 Hz**
- Electric actuators incrementally retracted between tests
- Data from **90** tests collected in total

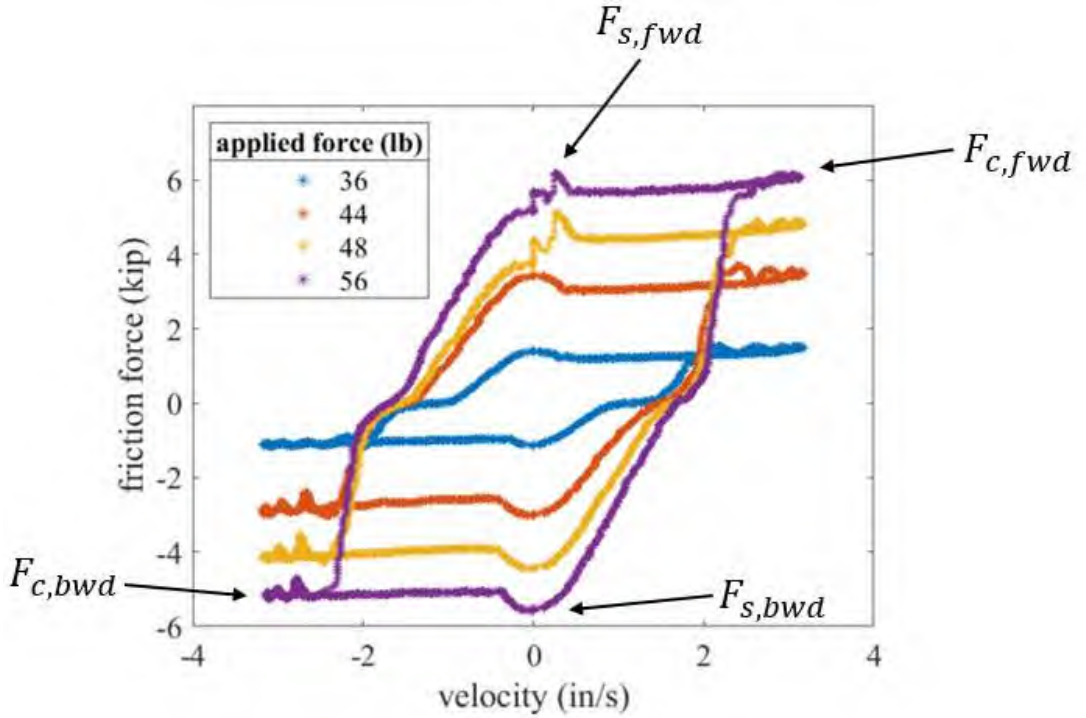
Actuator 1 position (in)

Actuator 2 position (in)	0.715	0.73	0.745	0.76	0.775	0.79	0.805	0.82	0.835
0.81									
0.825						x	x		
0.84					x	x	x	x	
0.855				x	x	x	x	x	
0.87			x	x	x	x	x	x	
0.885		x	x	x	x	x	x	x	
0.9	x	x	x	x	x	x*	x	x	
0.915		x	x	x	x	x	x	x	
0.93		x	x	x	x	x	x	x	
0.945									

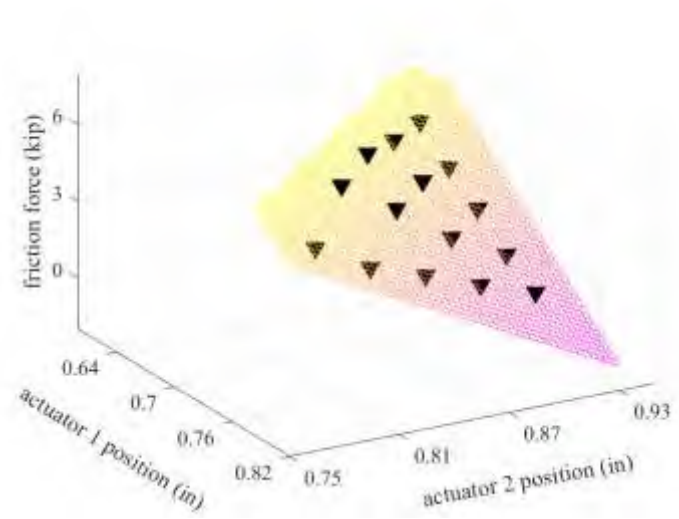
Full Test

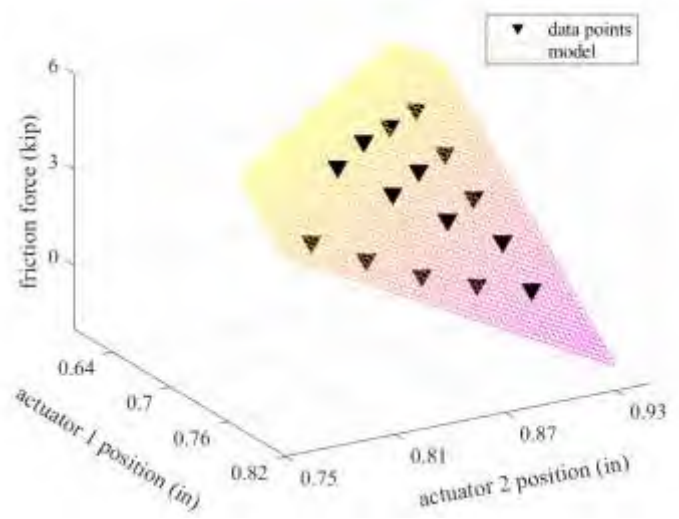
Safety Limit

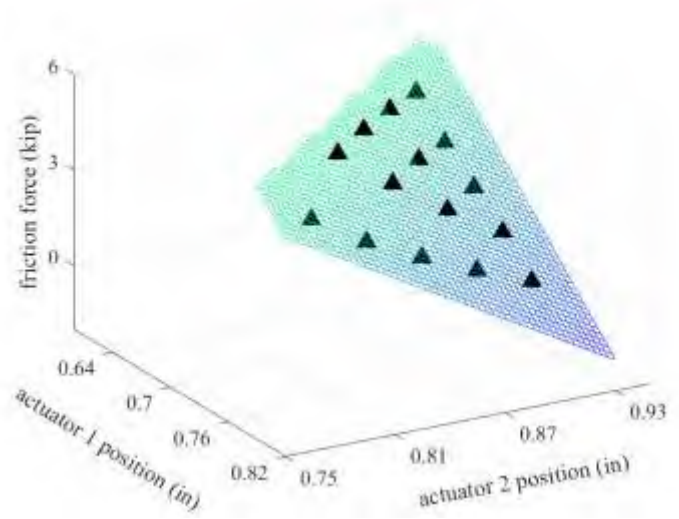
*conducted twice

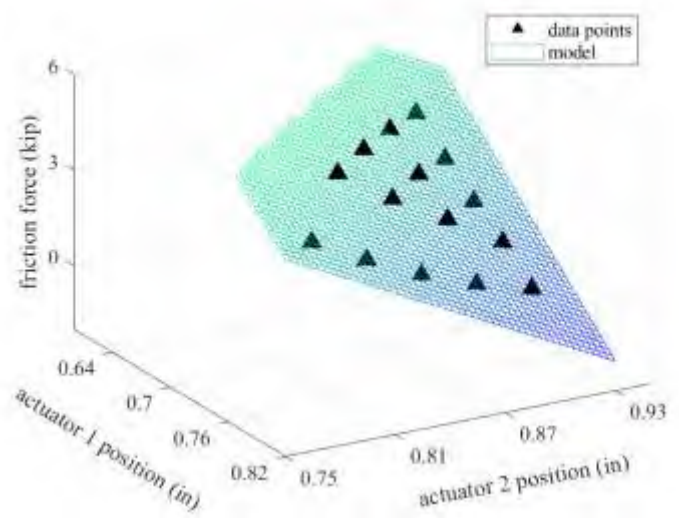


Regression Analysis





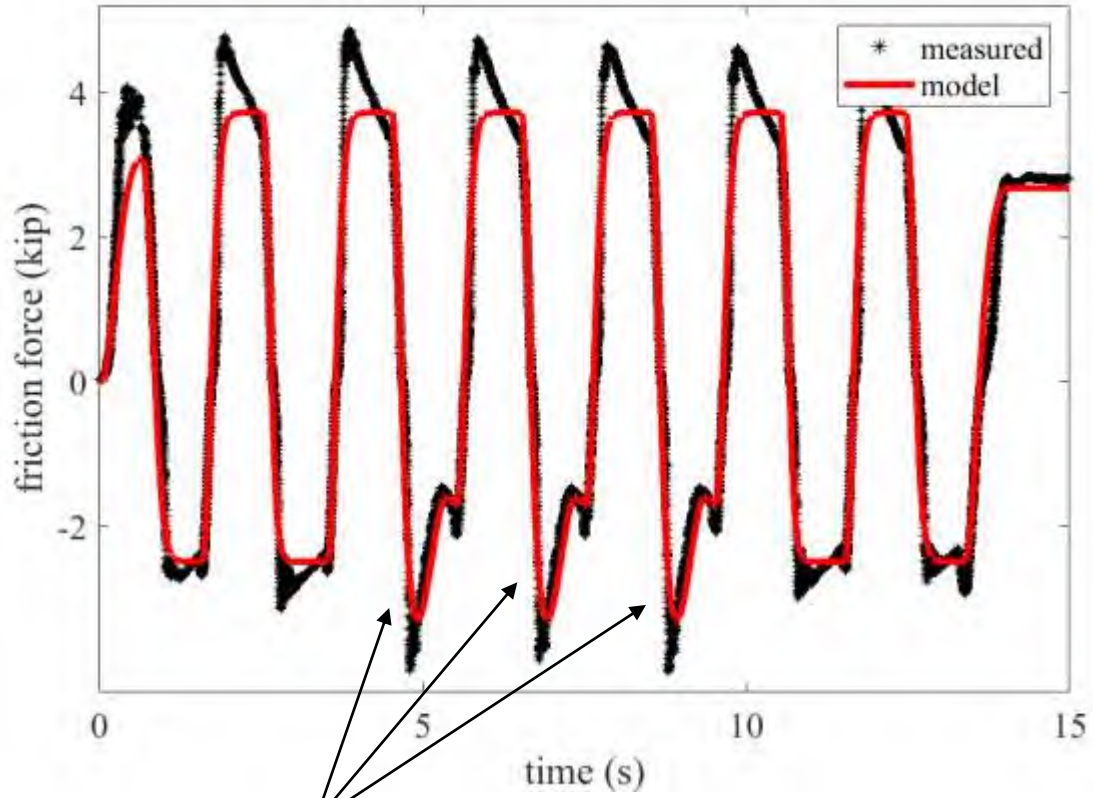




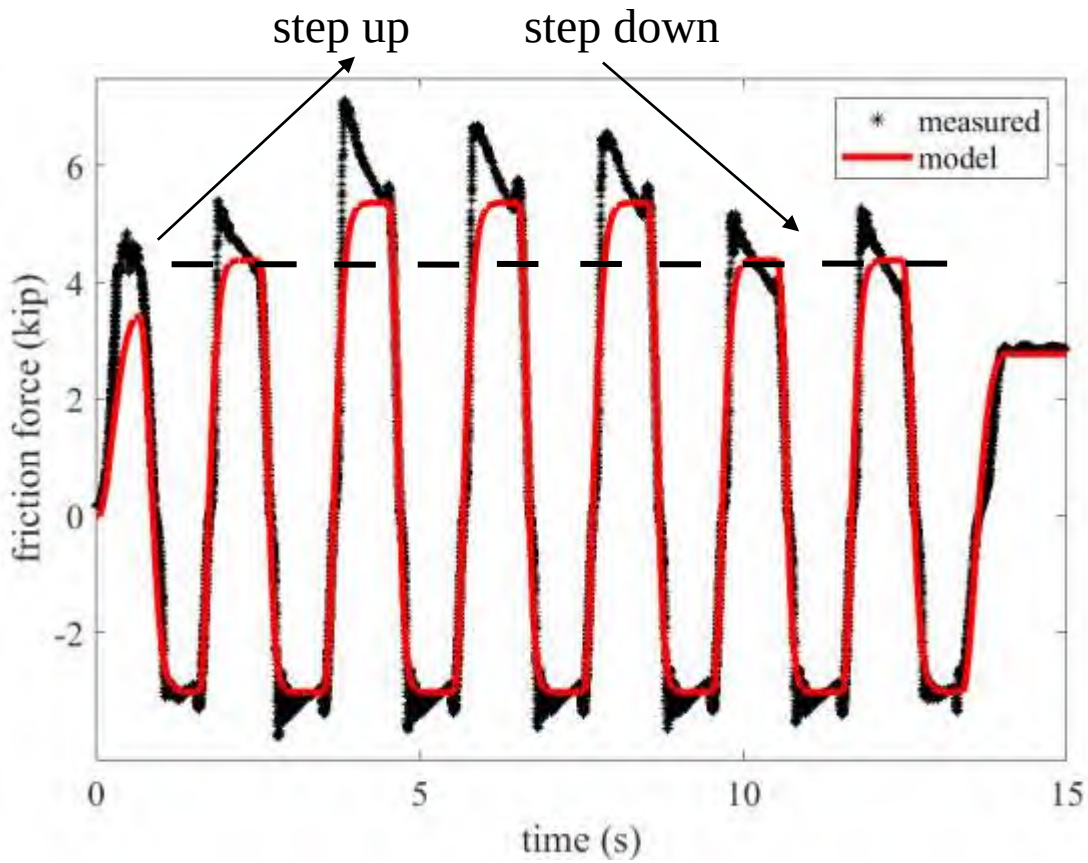
- Actuator initial positions **vs.** static/kinetic friction
- Slopes → rates at which damping changes with actuator **displacements**
- Linear models ignore potential for actuator coupling

Results

- Model able to predict changes in damping induced by electric actuator displacements



dynamic and



BRFD 2023 Lehigh

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THANK YOU!

WANT THE DATA?

https://github.com/ARTS-Laboratory/Dataset-Friction-Damper-with-Backlash

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Github-Lab: https://github.com/Arts-laboratory/

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