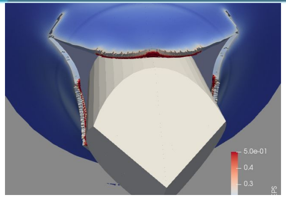
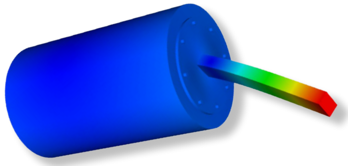
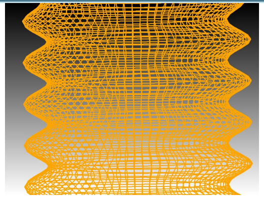
Quantifying the Effect of Non-Physical Parameters on the Nonlinear Dynamics of an Electromechanical Ratcheting Mechanism







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August 5th, 2025

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SAND2025-09714PE

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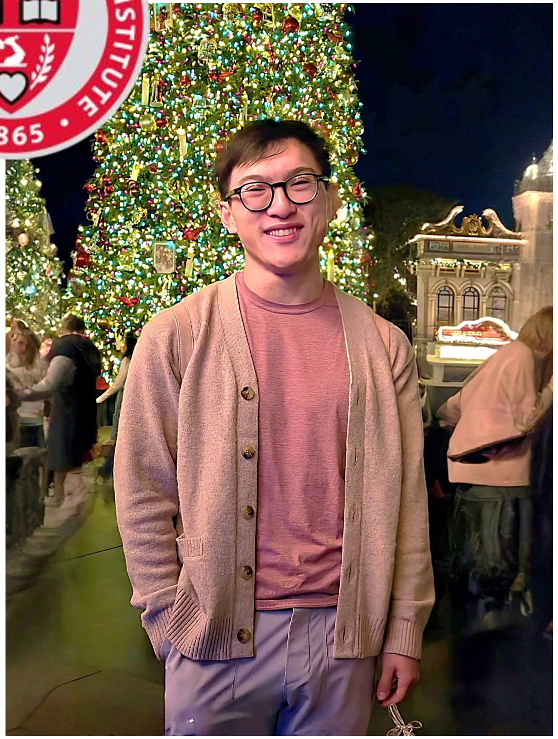

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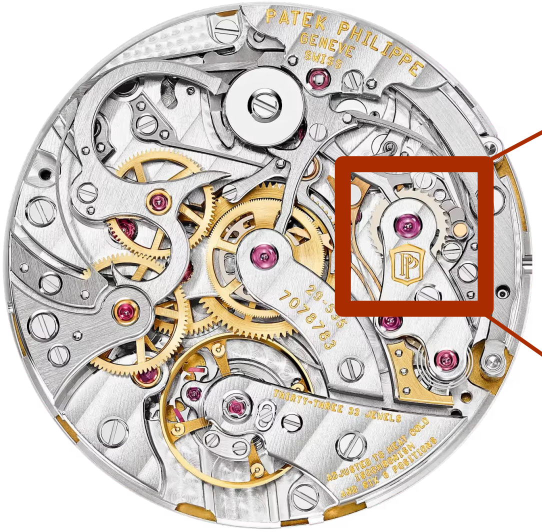
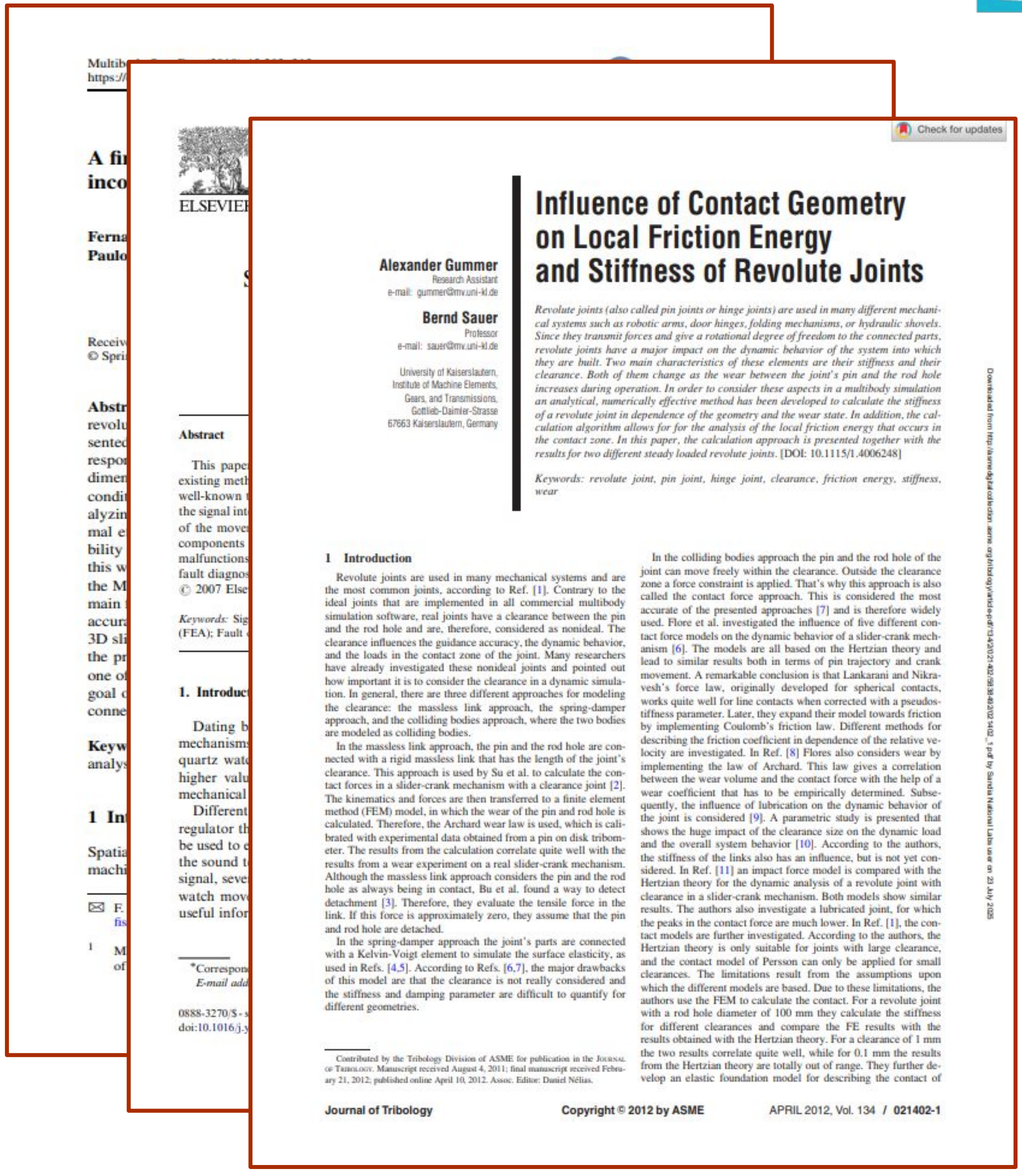
Background & Motivation

- Complex ratchet-like mechanisms exist in many commercial and aerospace applications.
- Previous work has looked at FEA’s sensitivity to nonphysical parameters by analyzing a single component.
- This work seeks to quantify the effect that these parameters have on multiple components that interact with each other.





Check for updates

Influence of Contact Geometry on Local Friction Energy and Stiffness of Revolute Joints

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Revolute joints (also called pin joints or hinge joints) are used in many different mechanical systems such as robotic arms, door hinges, folding mechanisms, or hydraulic shovels. Since they transmit forces and give a rotational degree of freedom to the connected parts, revolute joints have a major impact on the dynamic behavior of the system into which they are built. Two main characteristics of these elements are their stiffness and their clearance. Both of them change as the wear between the joint's pin and the rod hole increases during operation. In order to consider these aspects in a multibody simulation an analytical, numerically effective method has been developed to calculate the stiffness of a revolute joint in dependence of the geometry and the wear state. In addition, the calculation algorithm allows for for the analysis of the local friction energy that occurs in the contact zone. In this paper, the calculation approach is presented together with the results for two different steady loaded revolute joints. [DOI: 10.1115/1.4006248]

Keywords: revolute joint, pin joint, hinge joint, clearance, friction energy, stiffness, wear

1 Introduction

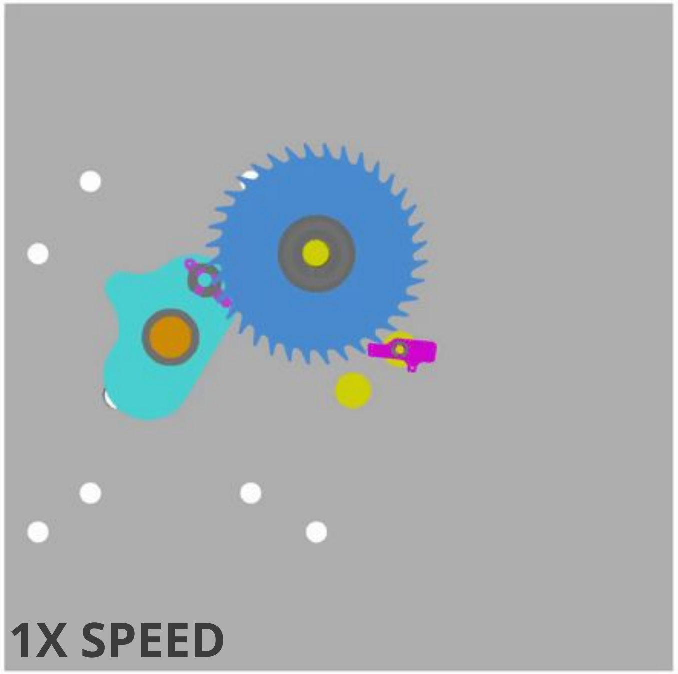
Image Credit: https://www.watchfinder.co.uk/articles/getting-technical-swiss-lever-escapement
https://www.patek.com/en/collection/movements/29-535

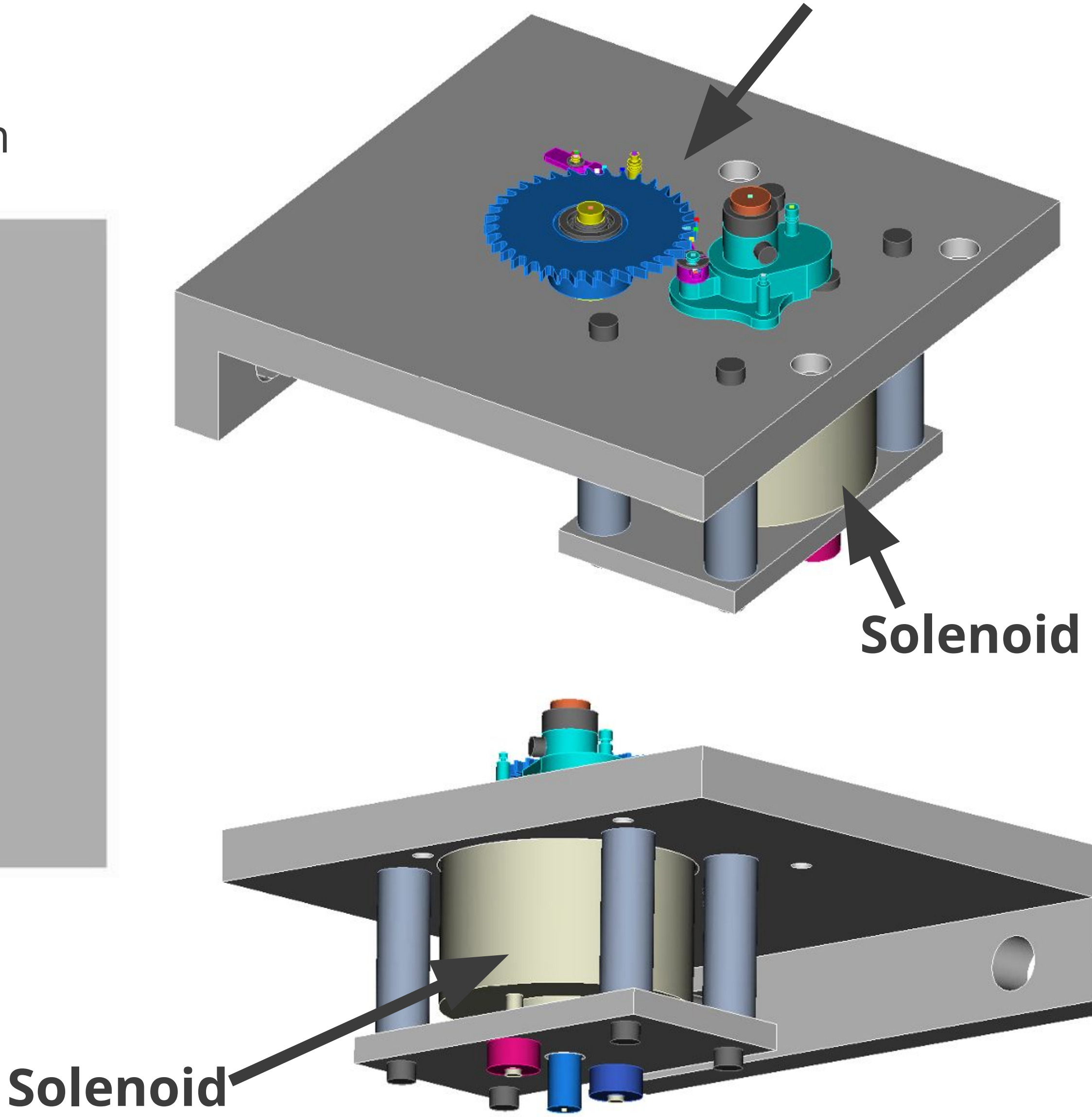
Ratcheting Mechanism Overview

BASEBALL AND NICKELS FOR SCALE

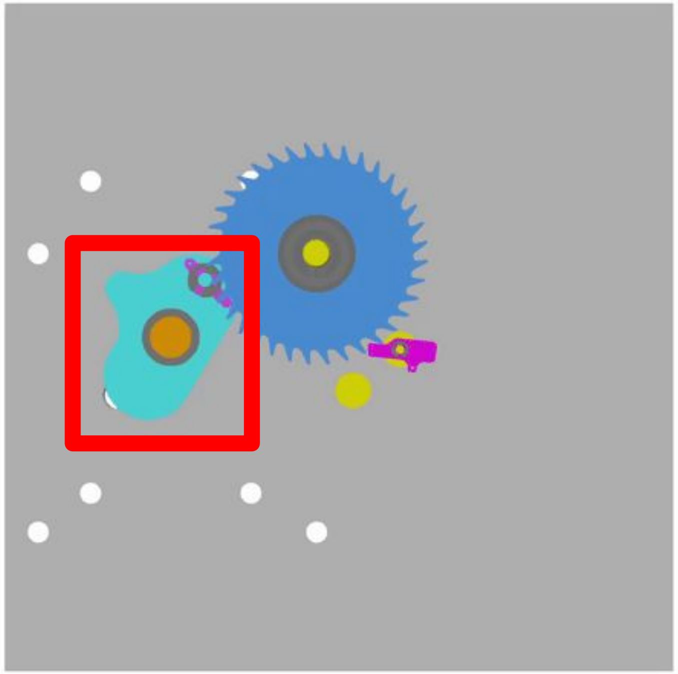
https://en.wikipedia.org/wiki/Baseball_%28ball%29

Multibody Simulation (MATLAB)





Ratcheting Mechanism Overview



Drive Arm and Drive Pawl

- Drive arm is actuated via solenoid
- Drive pawl rotates via drive spring
- The size of a nickel

Nickel

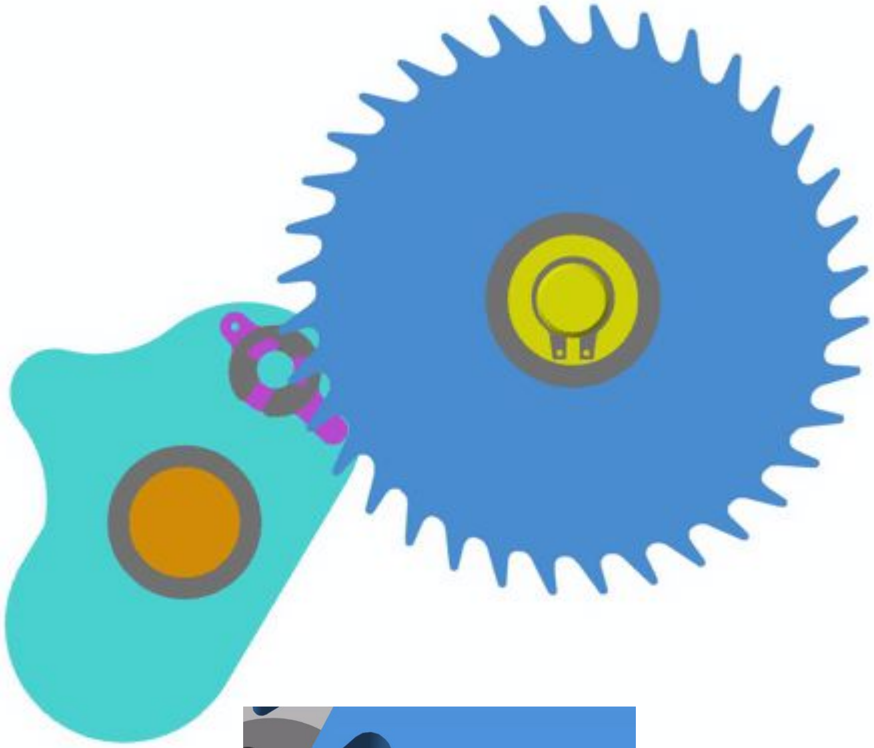
0.1X SPEED
(Drive spring not shown in animation)

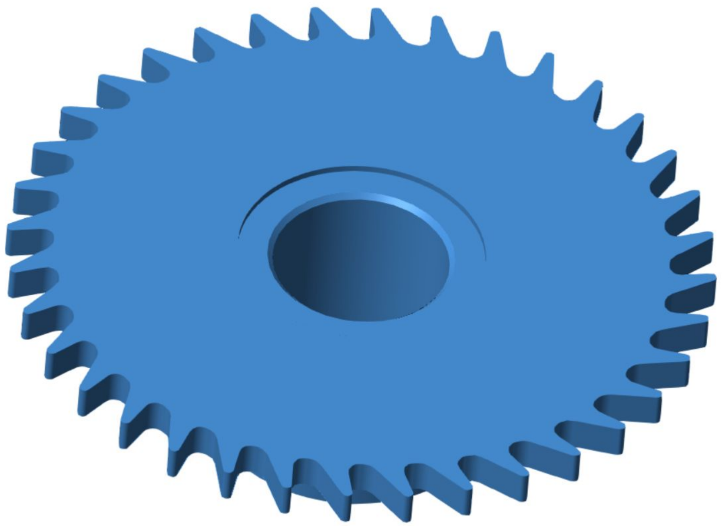
https://www.istockphoto.com/photos/close-up-of-jefferson-nickel

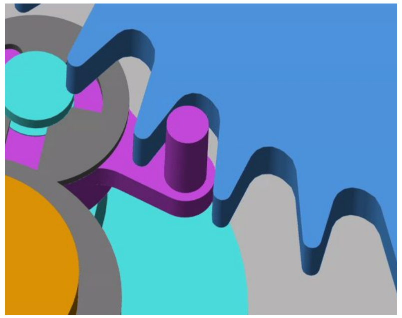
Drive Arm and Drive Pawl and Ratchet Wheel

- Ratchet Wheel rotated via Drive Pawl

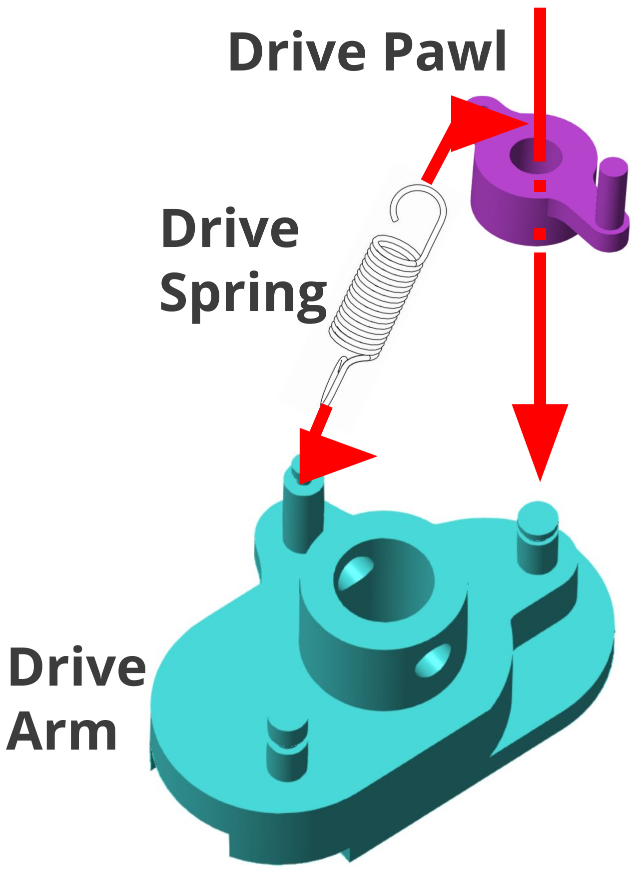
Nickel

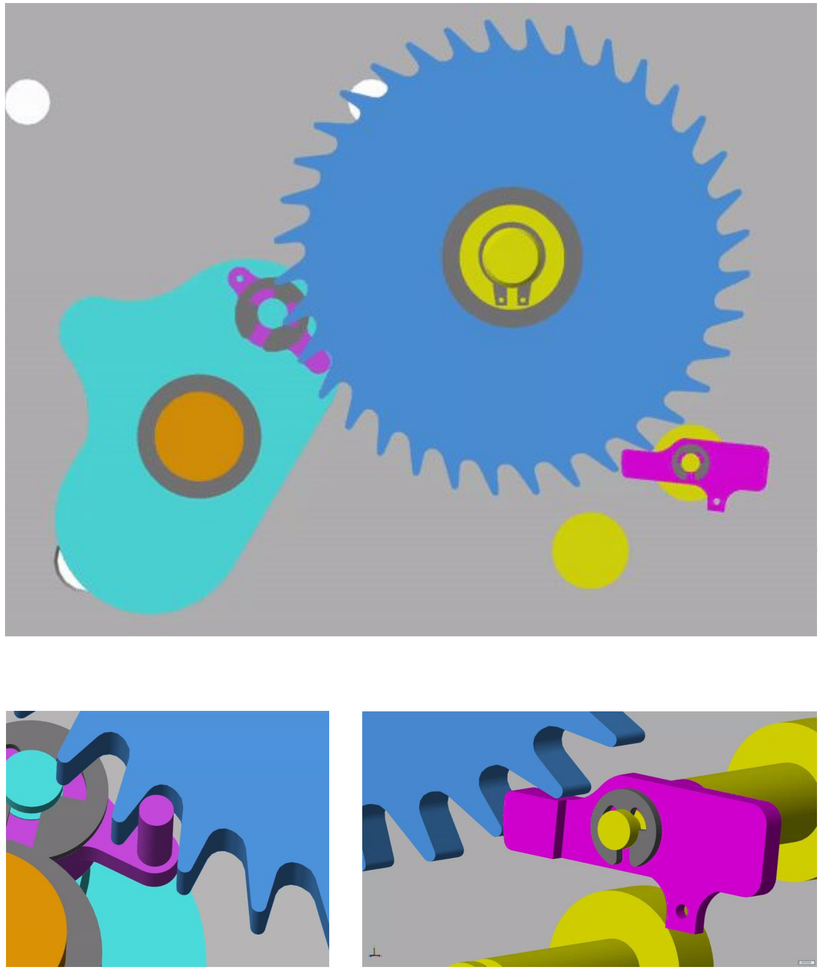


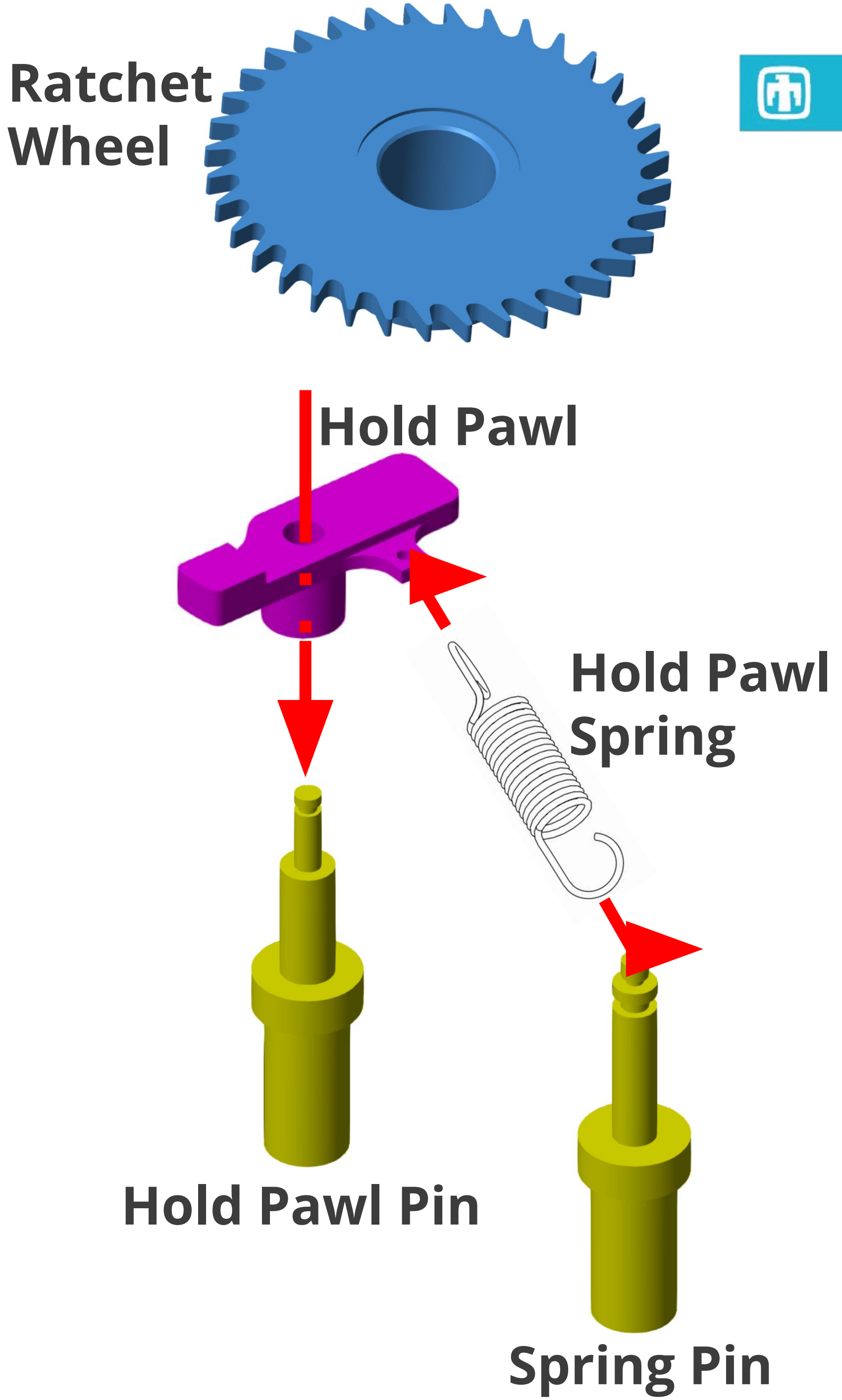




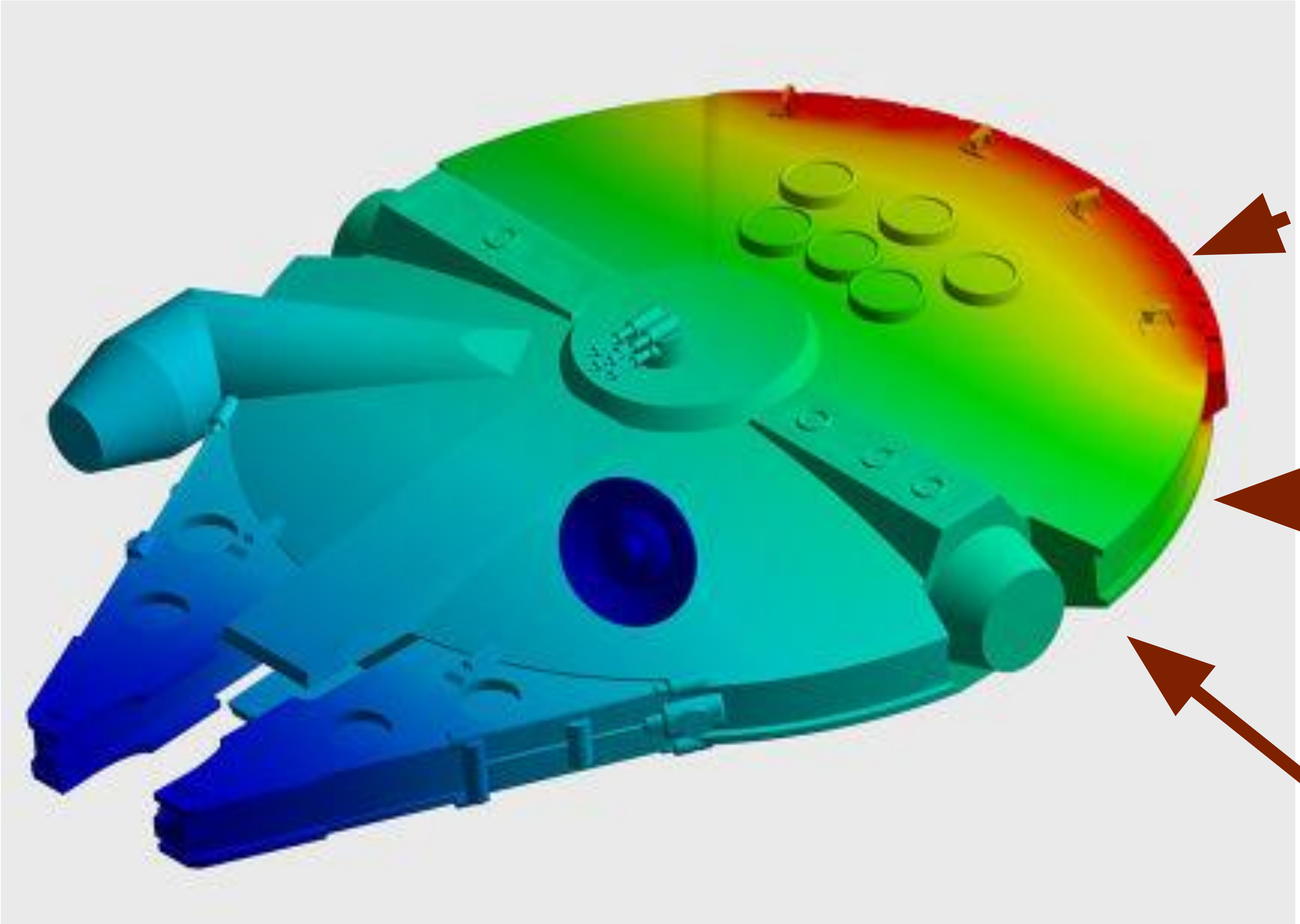
Ratcheting Mechanism Components

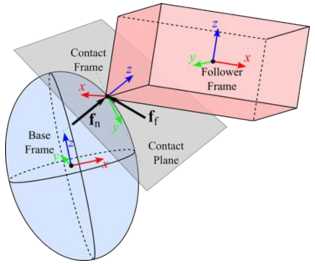






Finite Element Method

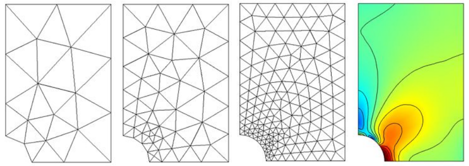




Momentum Balance Iterations

- Calculate and apply contact force to minimize penetration distance

Mesh Density



- Typically, a finer mesh results in better solution but increases computation cost

Processor Count

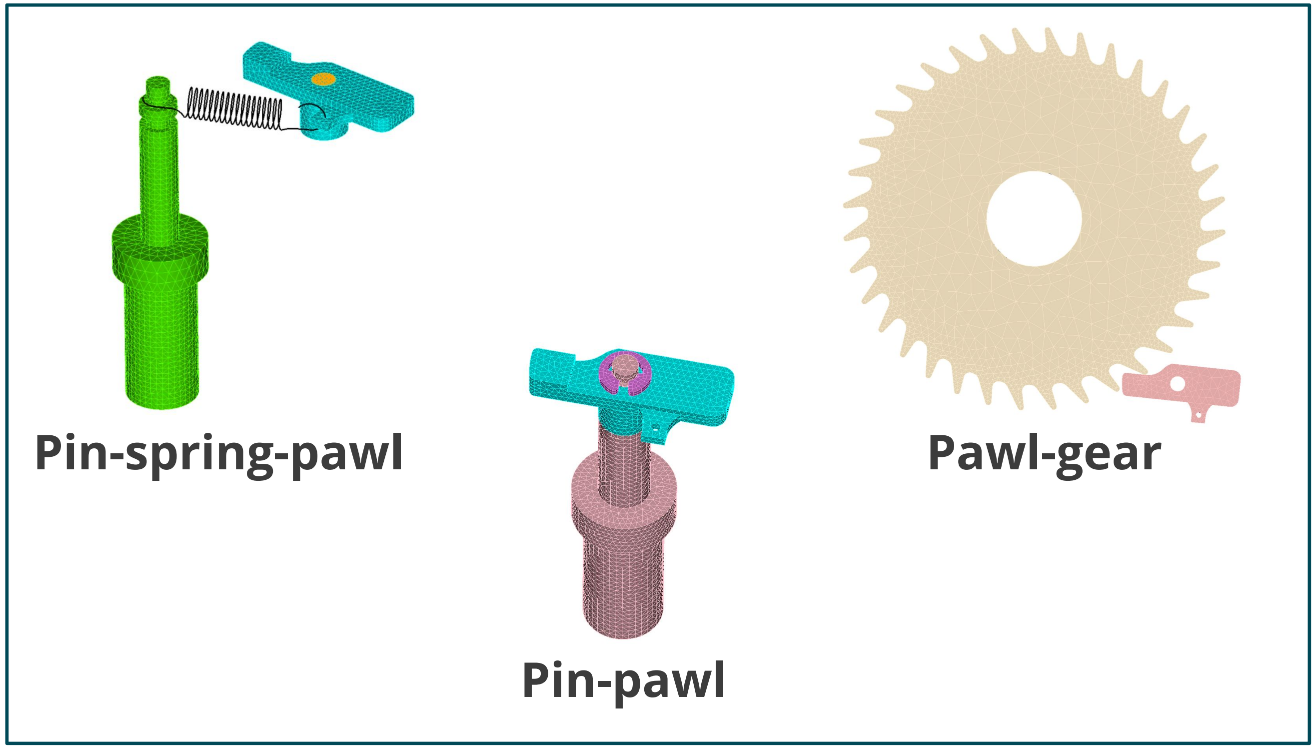
- Analysis is split up between multiple parallel processors to speed up processing

https://fetchcfd.com/view-project/2453-thermal-simulation-millennium-falcon
https://study.com/academy/lesson/what-is-momentum-definition-equation-units-principle.html
https://www.comsol.com/blogs/meshing-considerations-linear-static-problems

Project Overview

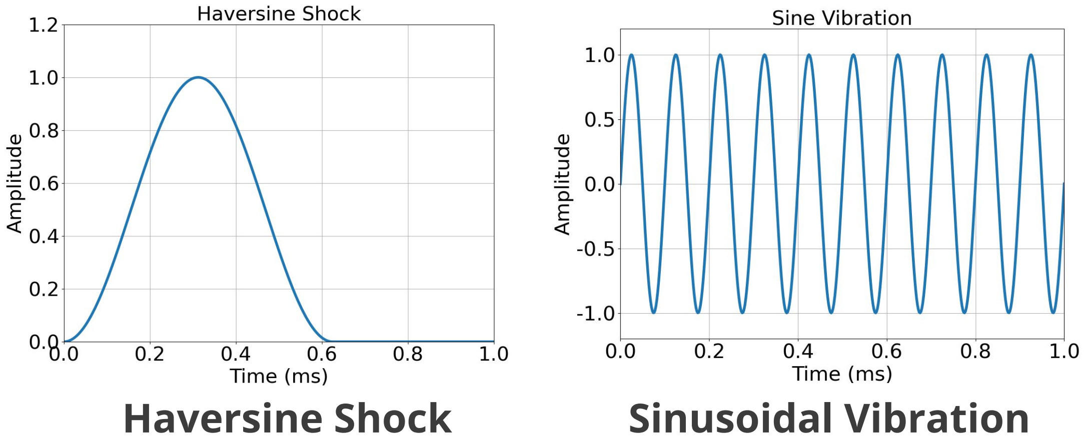
- **Conduct parameter studies on small submodels of the ratcheting mechanism**
- **Find out how changing parameters affect a ratcheting mechanism experiencing different excitation environments**

Submodels



Momentum Balance Iterations: 1, 5, 10, 20, 50, 75, 100
Mesh Density: Fine, Nominal, Coarse, Very Coarse
Processor Count: 50%, 100%, 150%, 200%, 250%

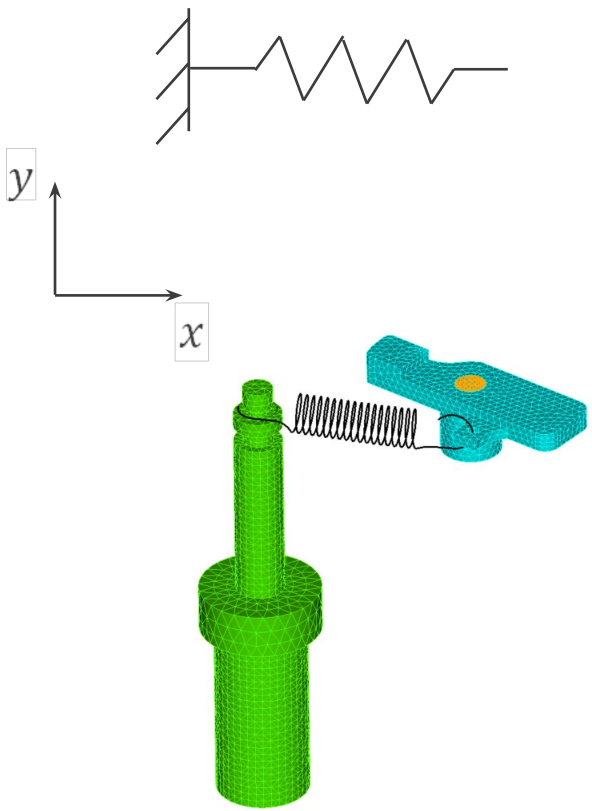
Environments:



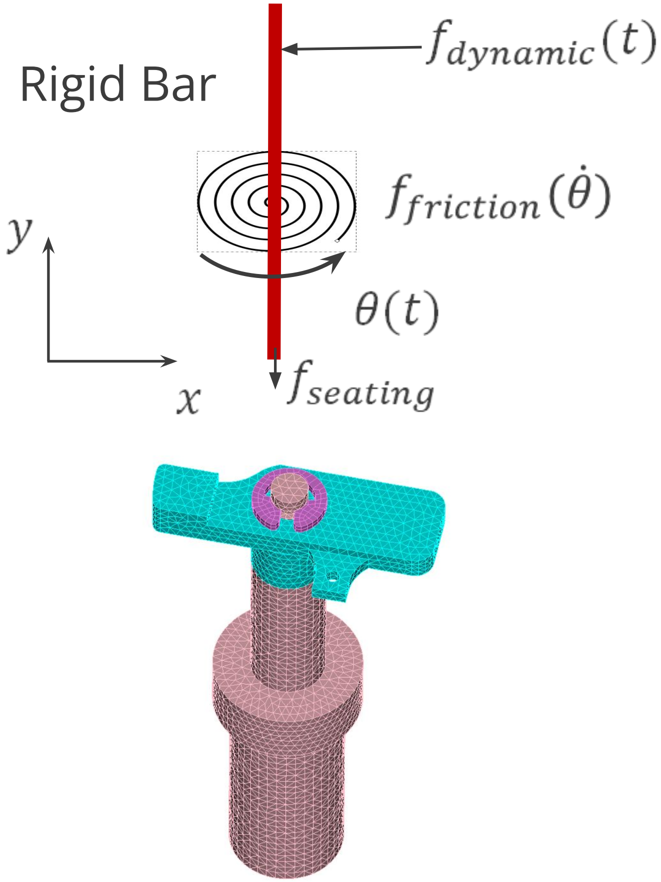
(Unit amplitude shown)

Idealized Model

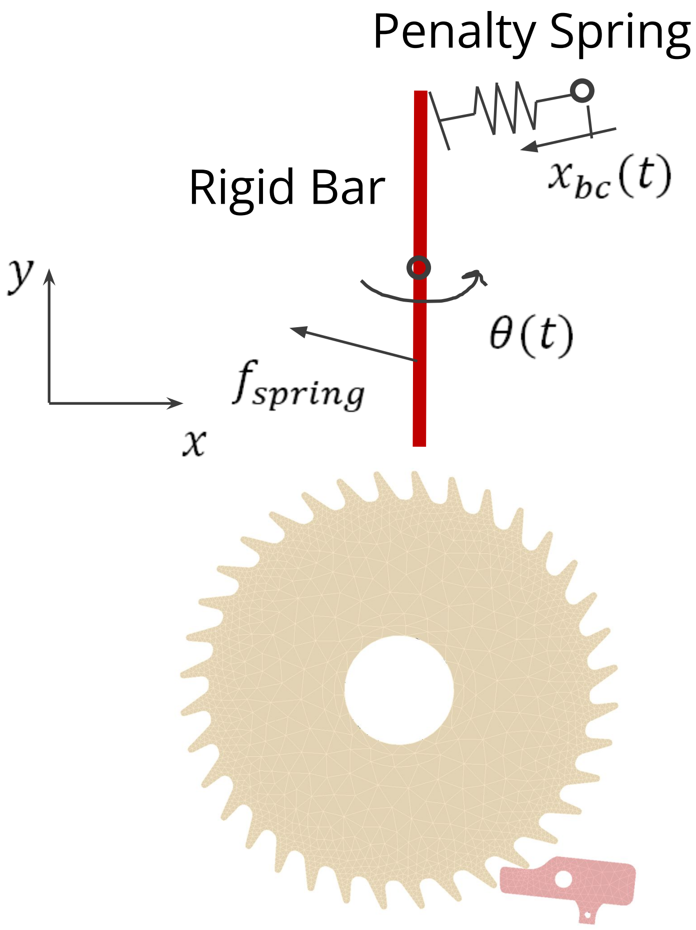
- **A simplified approximation of a system for quick and easy analysis**



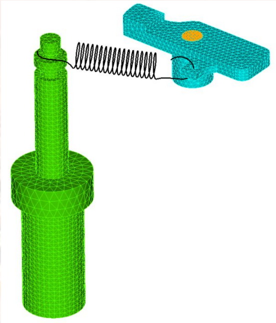
Pin-spring-pawl



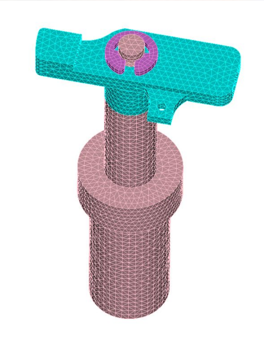
Pin-pawl



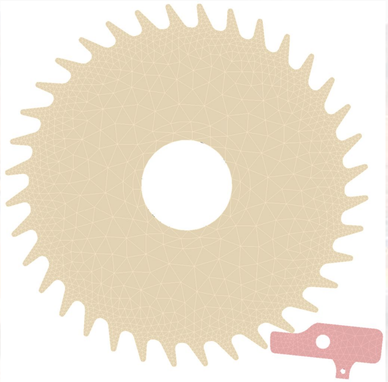
Pawl-gear



Pin-spring-pawl



Pin-pawl



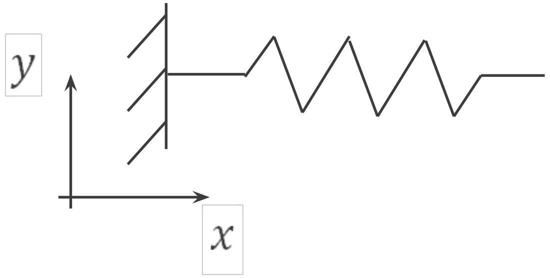
Pawl-gear

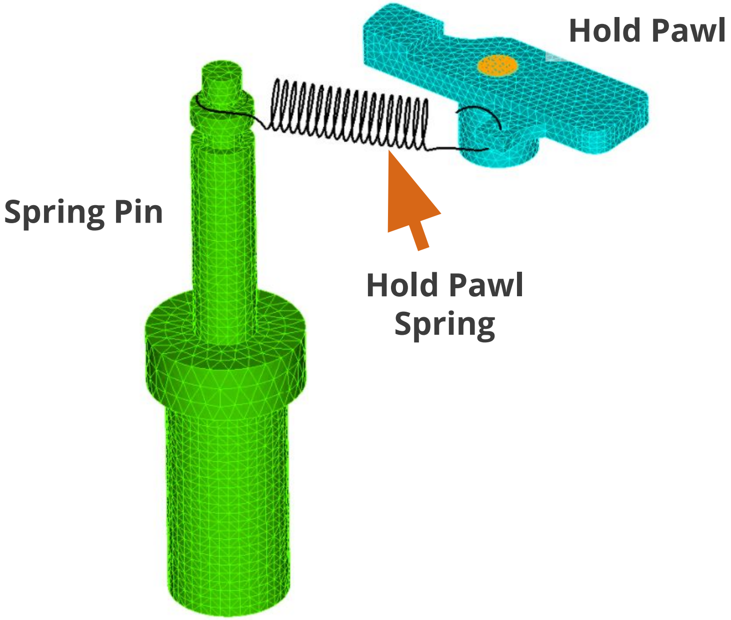
Submodel – Pin-Spring-Pawl

Pin-Spring-Pawl Submodel

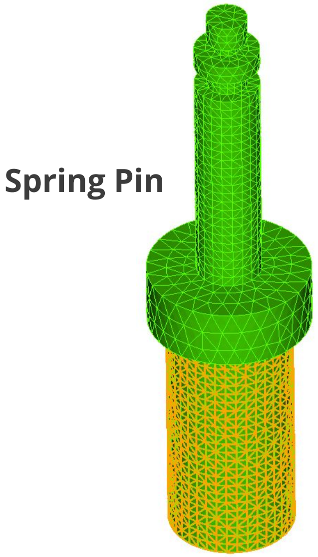
- **Boundary Conditions**
  - Base of Pin is fixed in all degree's of freedom
  - Center of pawl is displaced in the axial direction of the spring
- **Quantities of Interest**
  - Contact force on Hold Pawl and Spring Pin

Idealized Model:

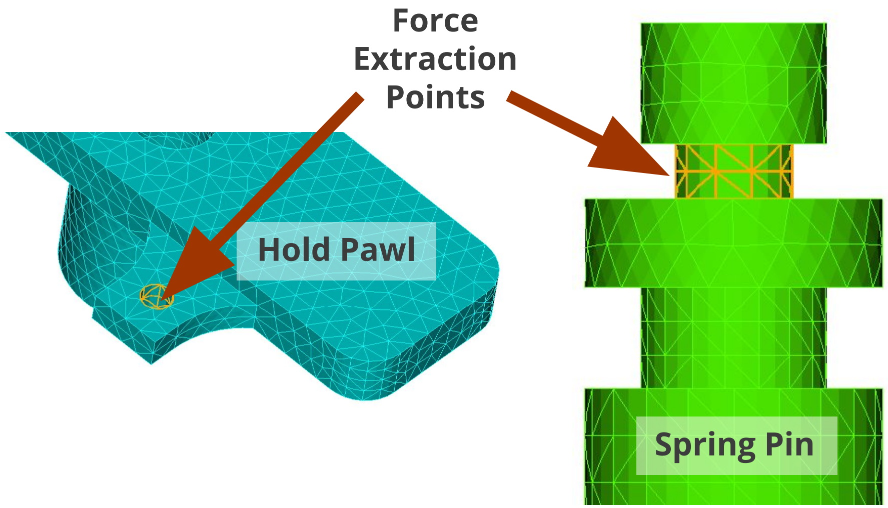




Prescribed displacement to the Hold Pawl in the axial direction of the spring



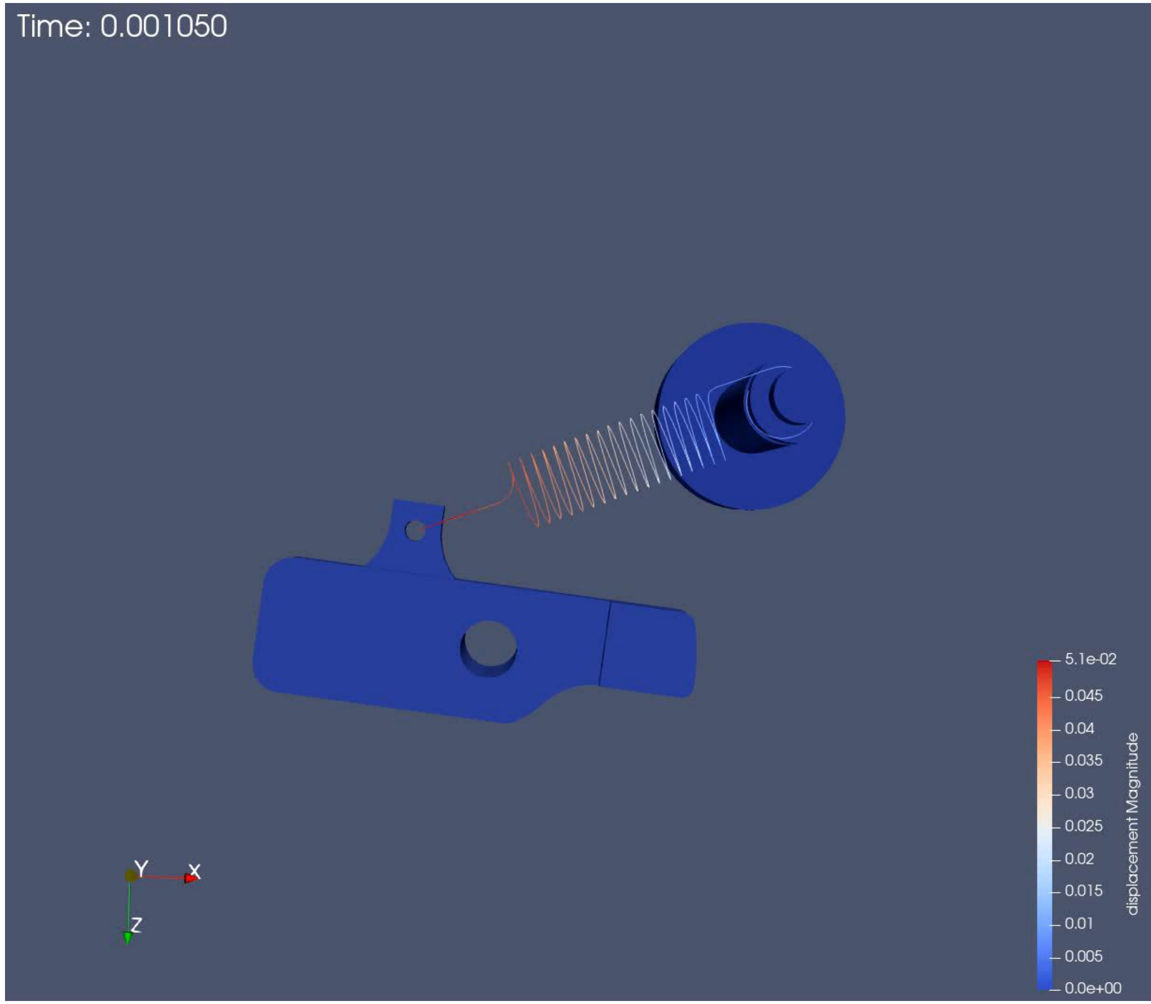
Base of Pin is fixed in all DOF's.



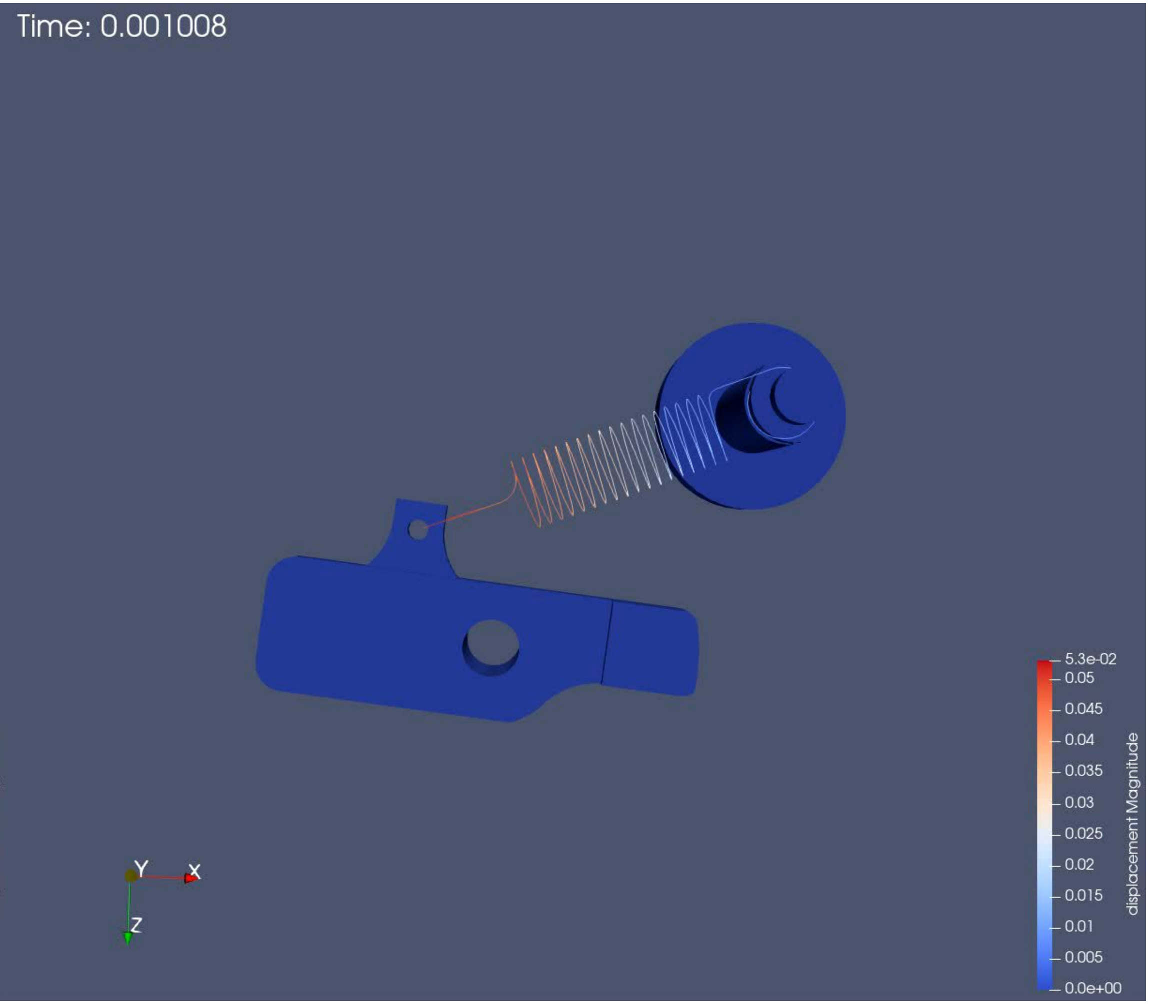
Force Extracted Where Spring Interacts with the Pin and Pawl

Pin-Spring-Pawl Environments

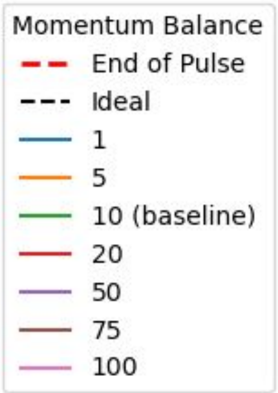
Haversine Shock

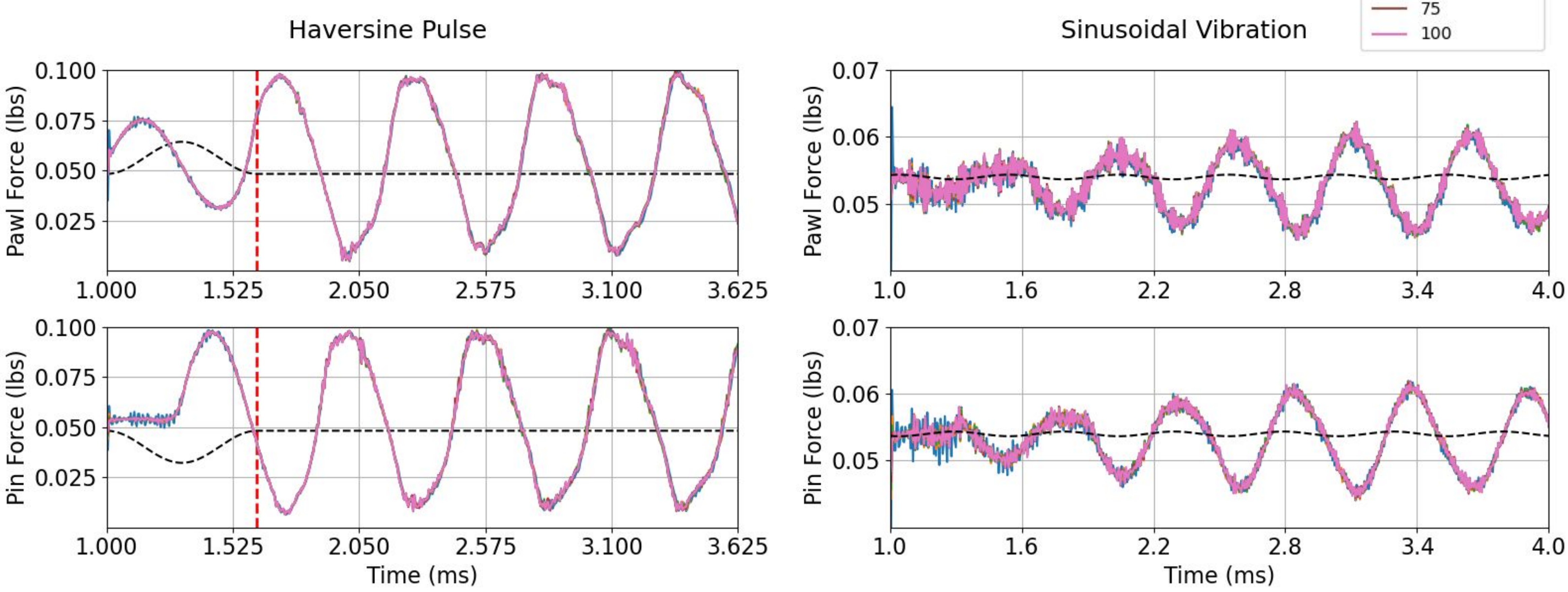


Sinusoidal Vibration



Momentum Balance Iteration – Pin-Spring-Pawl

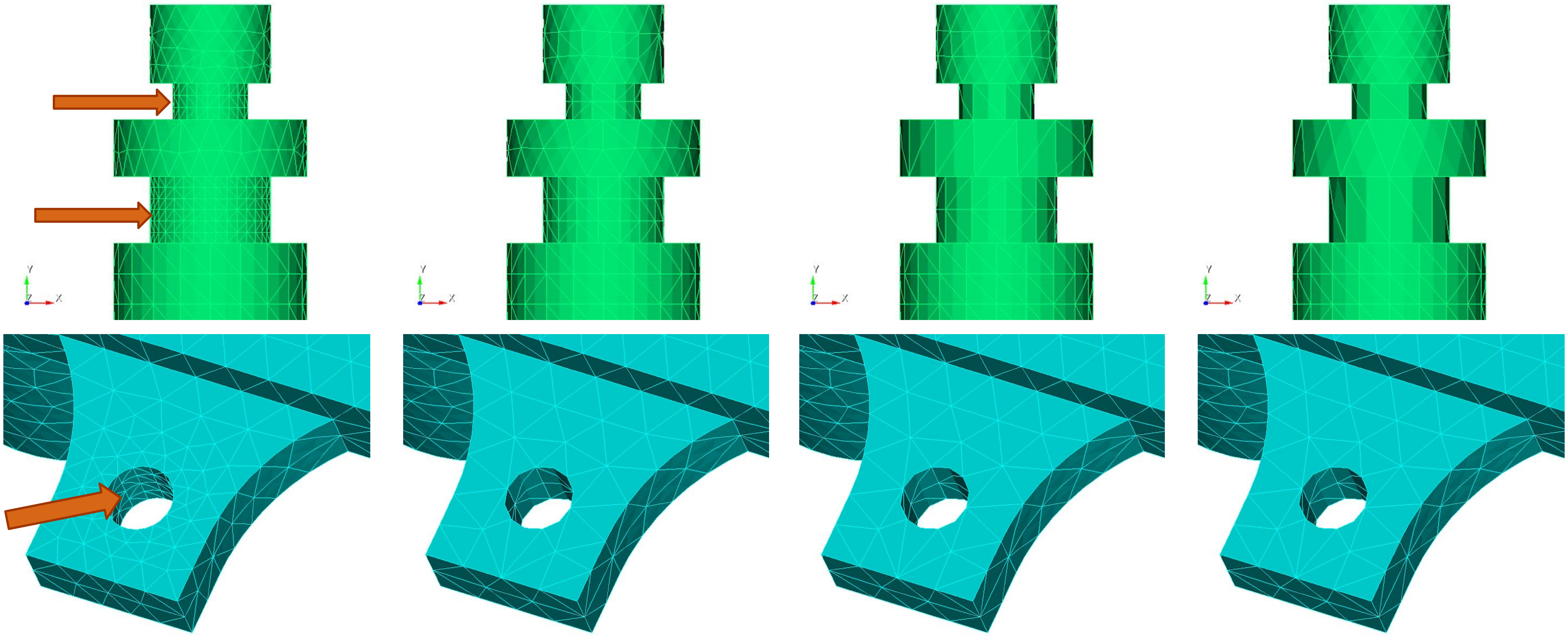




- Submodel is not sensitive to the number of momentum balance iterations used during analysis
- Ideal model needs adjustments to make accurate predictions of dynamics

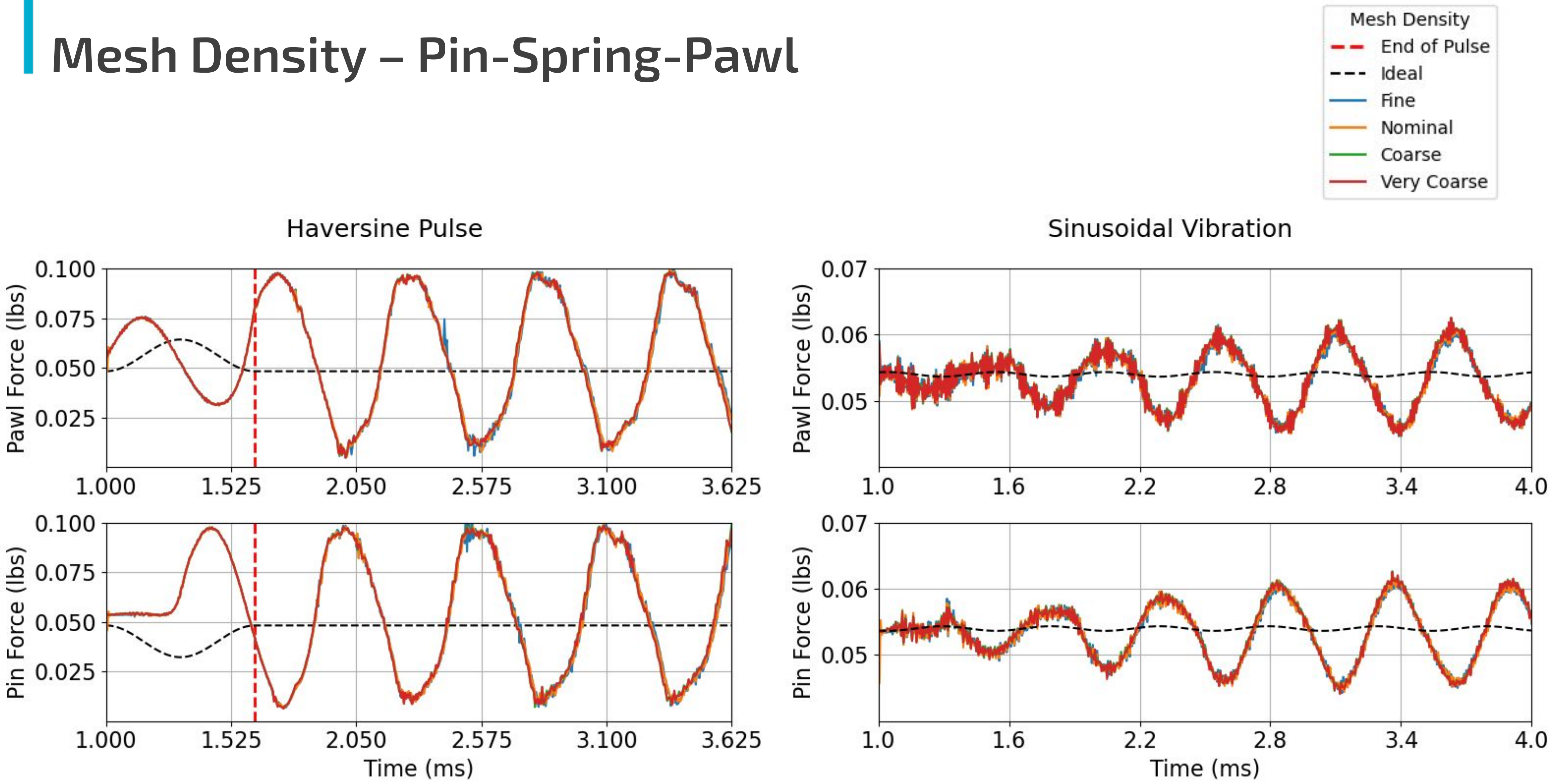
Mesh Density – Pin-Spring-Pawl

Fine | Nominal | Coarse | Very Coarse



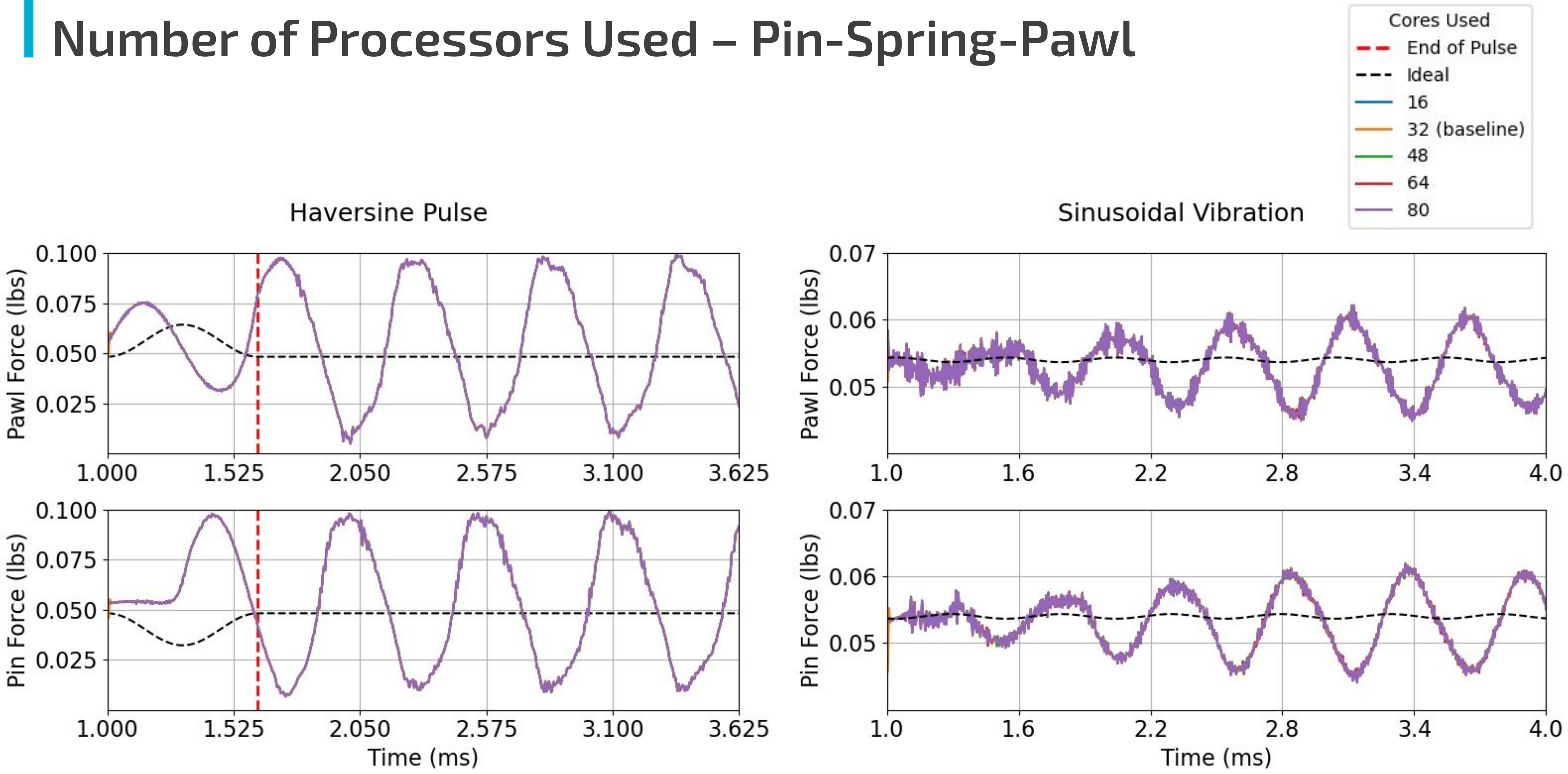
35655 Elements | 28827 Elements | 27618 Elements | 27410 Elements

Mesh Density – Pin-Spring-Pawl

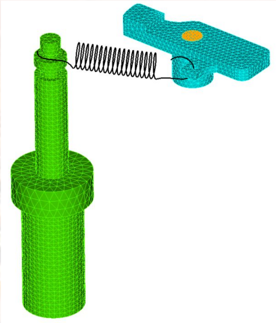


- Increasing or decreasing mesh density at the interface does not affect results
  - It could be possible to use larger elements to speed up simulation time

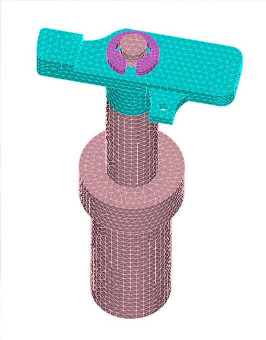
Number of Processors Used – Pin-Spring-Pawl



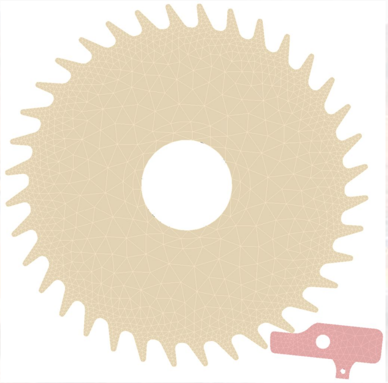
- Submodel is insensitive to the number of cores used



Pin-spring-pawl



Pin-pawl



Pawl-gear

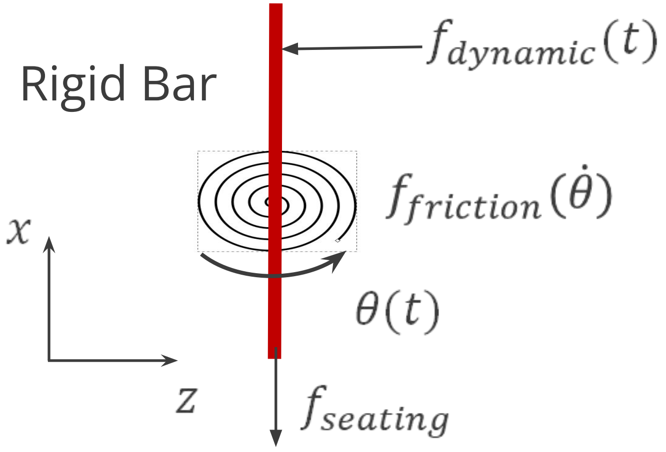
Submodel – Pin-Pawl

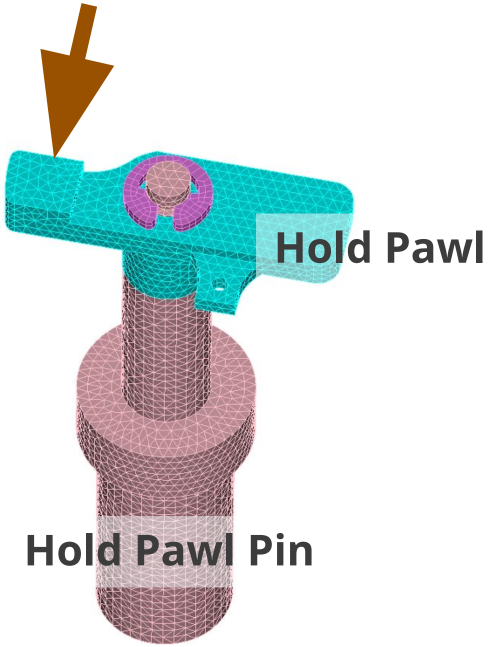
Pin-Pawl Submodel

Parts:
- Hold pawl
- Hold pawl pin

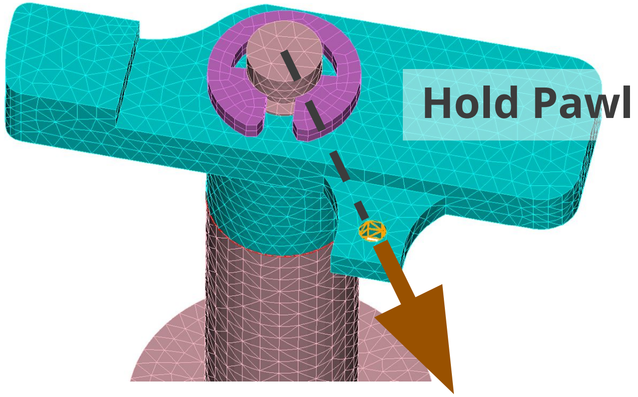
Quantities of interest:
- Contact force between pin and pawl
- Pawl rotation angle

Idealized Model:
- Center of mass and inertia from FE model

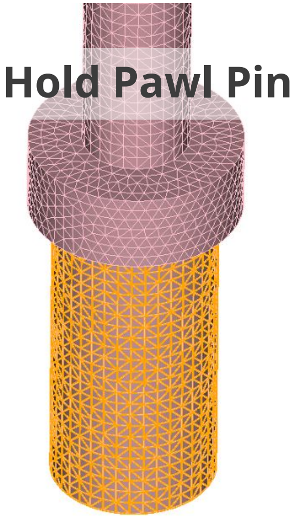




Pressure (shock or vibration) applied to side of pawl



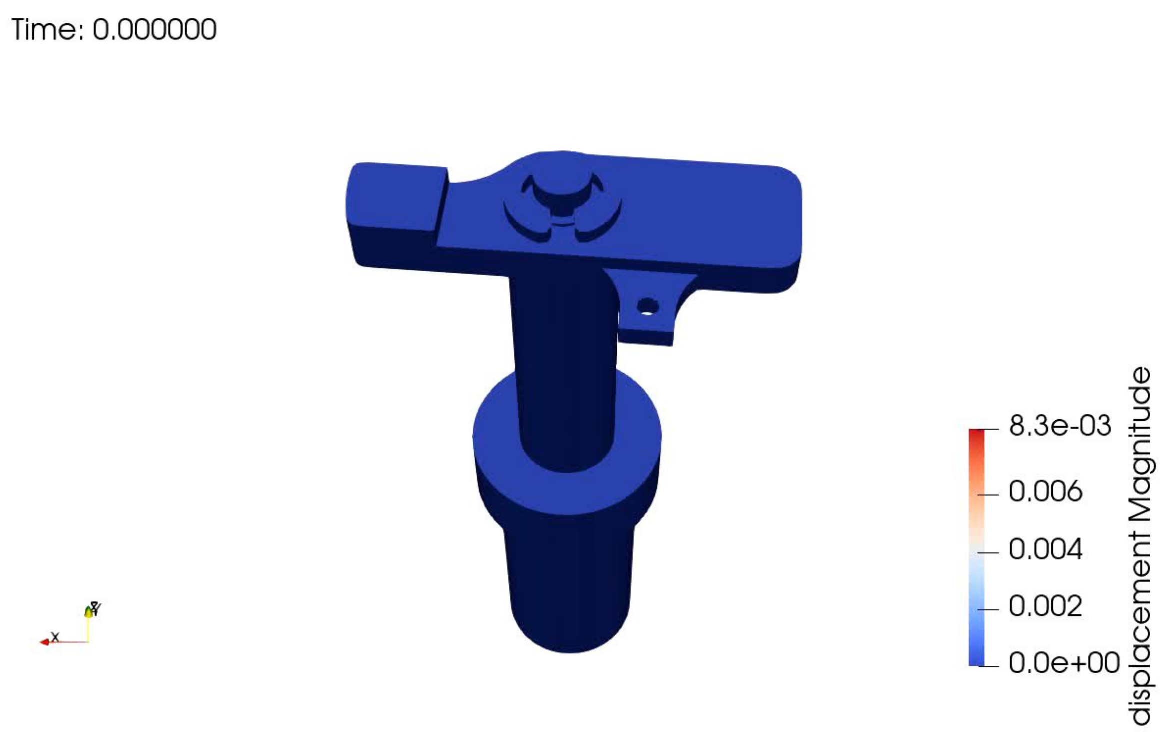
Constant seating force applied in one direction



Base of pin is fixed in all DOF's

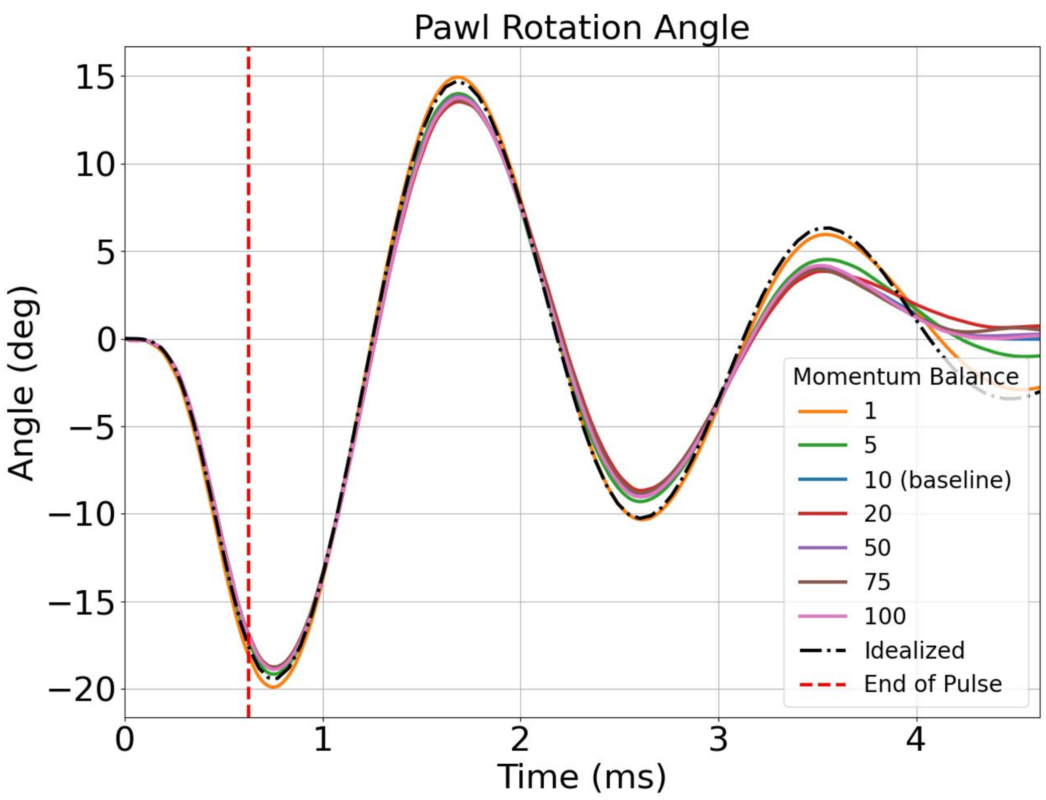
Pin-Pawl Environments

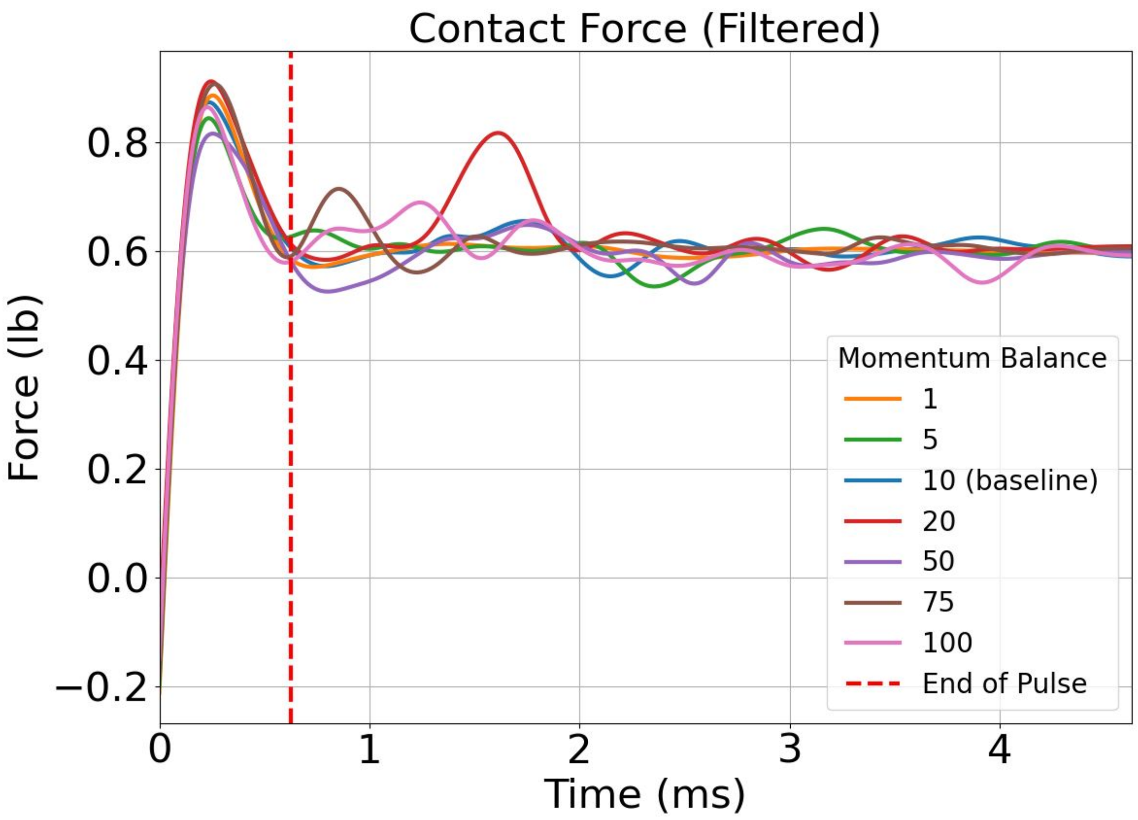
Haversine Shock



Sinusoidal Vibration

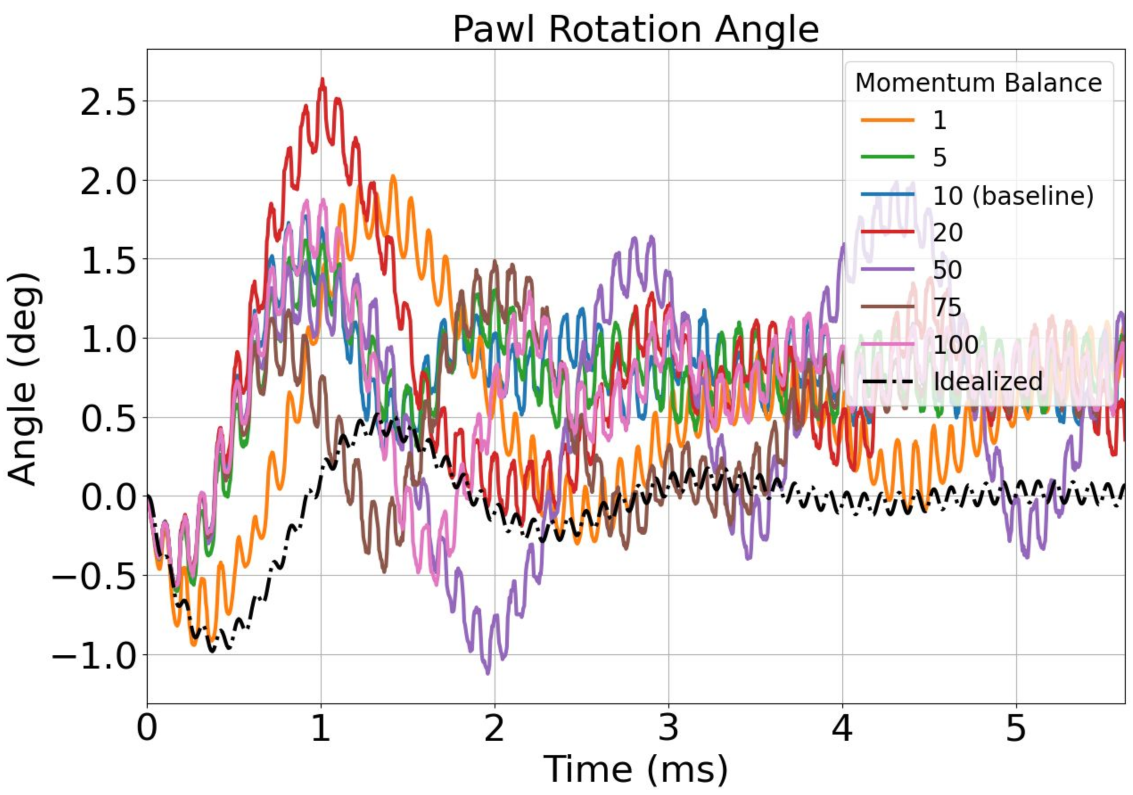
Momentum Balance Iteration – Pin-Pawl (Haversine Shock)

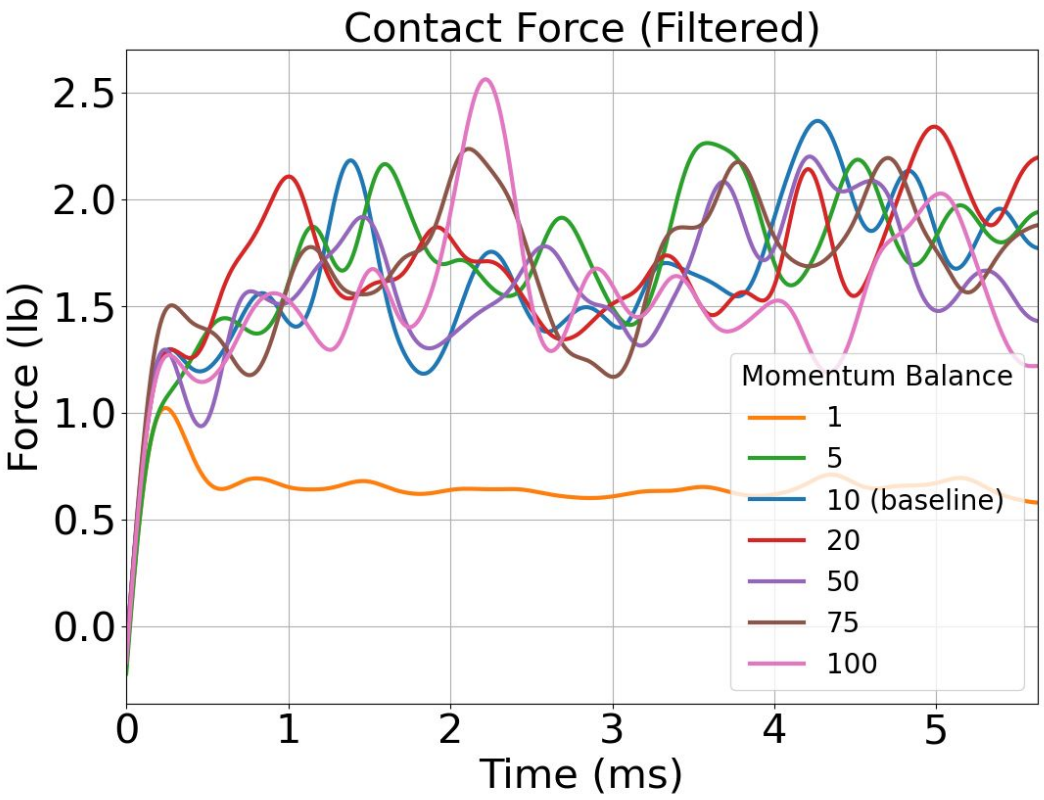




- Rotations agree with idealized model
- Rotations diverge after shock as contact and friction dictate motion
- Contact force is erratic

Momentum Balance Iteration – Pin-Pawl (Sinusoidal Vibration)

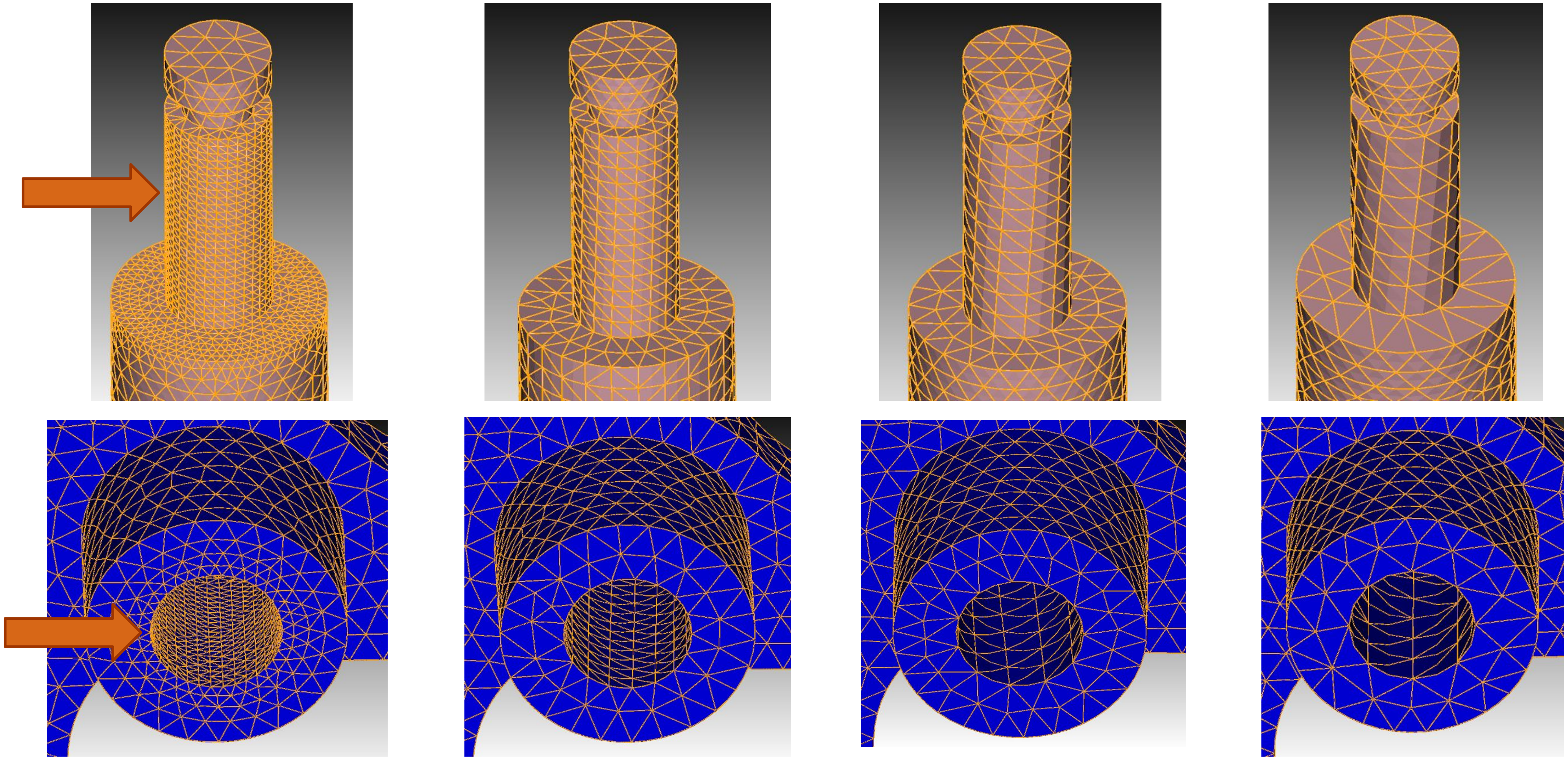




- Larger amplitude compared to idealized model, but otherwise similar profile
- Rotation and contact force are erratic
- Sensitive to momentum balance iteration

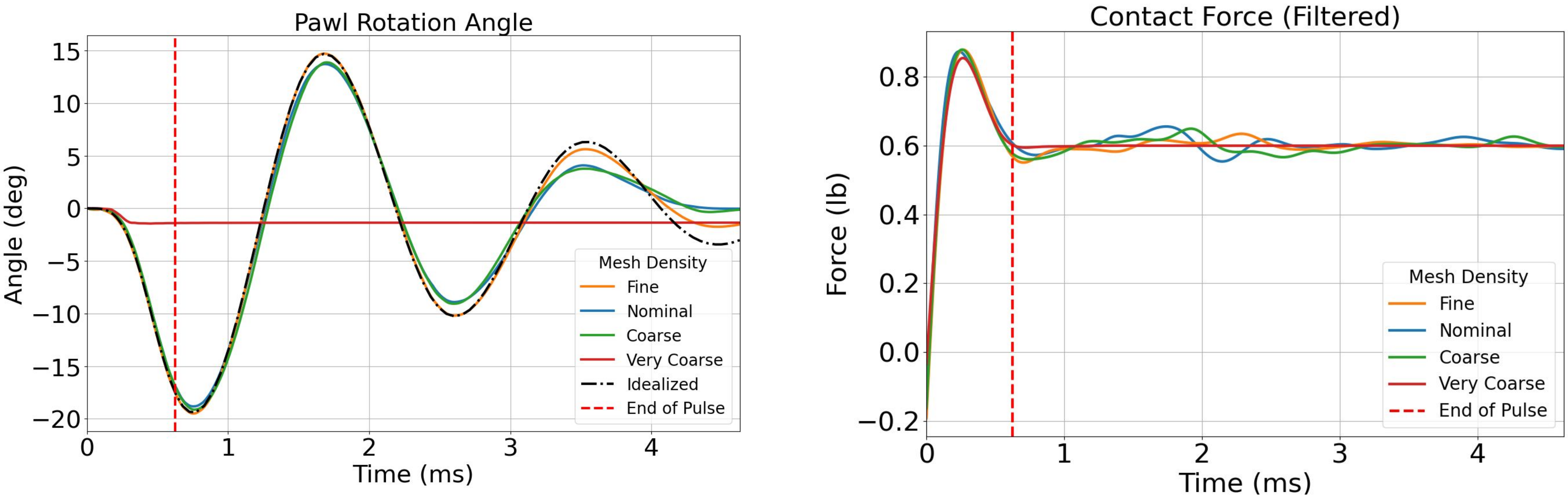
Mesh Density – Pin-Pawl

Fine | Nominal | Coarse | Very Coarse



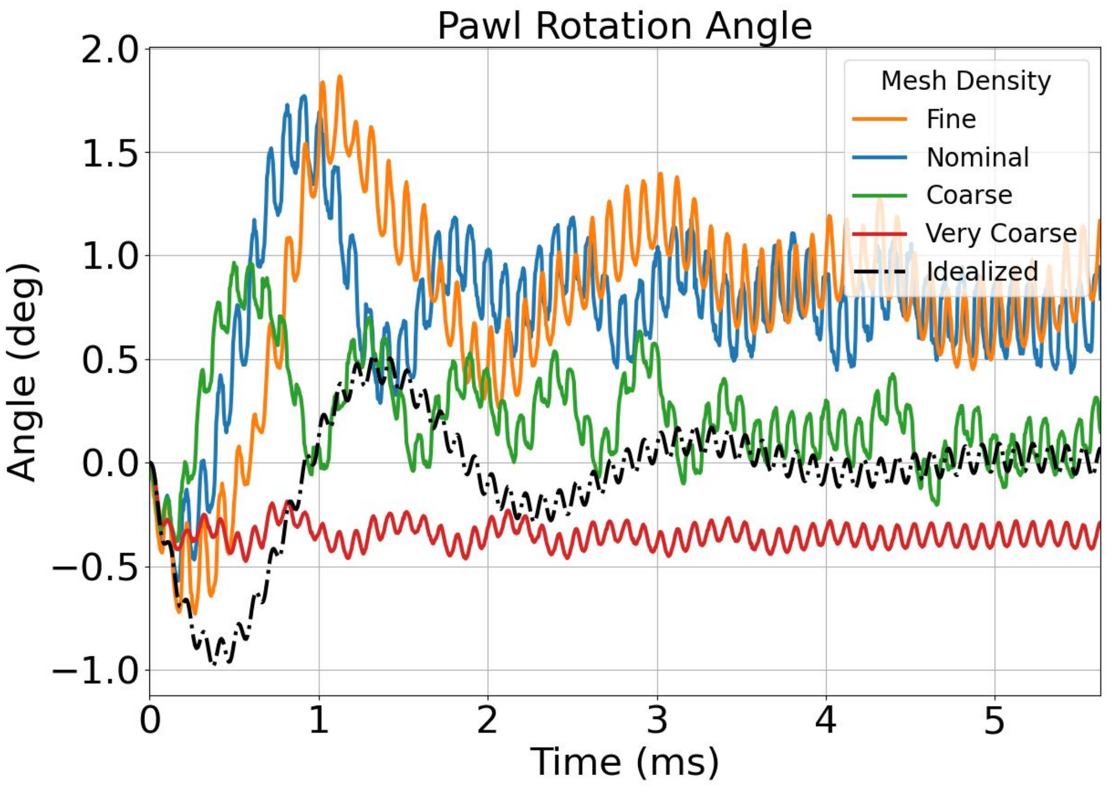
65763 Elements | 46310 Elements | 45025 Elements | 43909 Elements

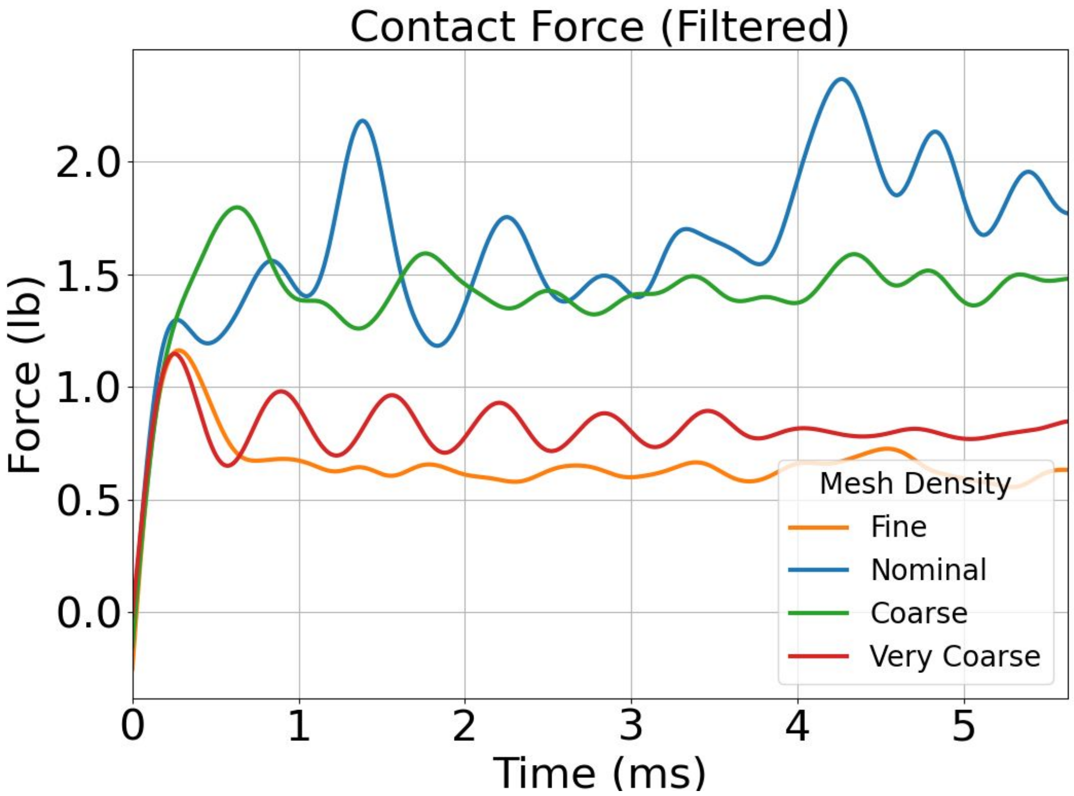
Mesh Density – Pin-Pawl (Haversine Shock)



- Rotations roughly agree with idealized model
- Rotation lock-up for very coarse mesh density
- Rotations diverge after shock
- Contact force is erratic

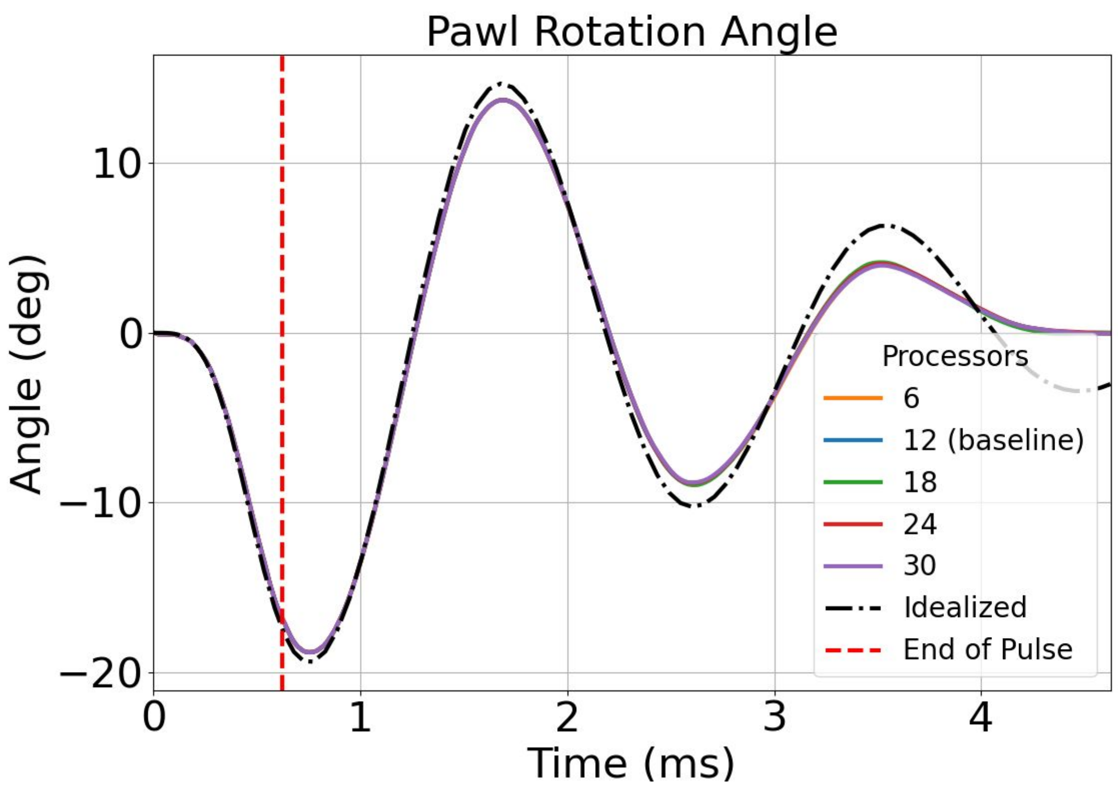
Mesh Density – Pin-Pawl (Sinusoidal Vibration)

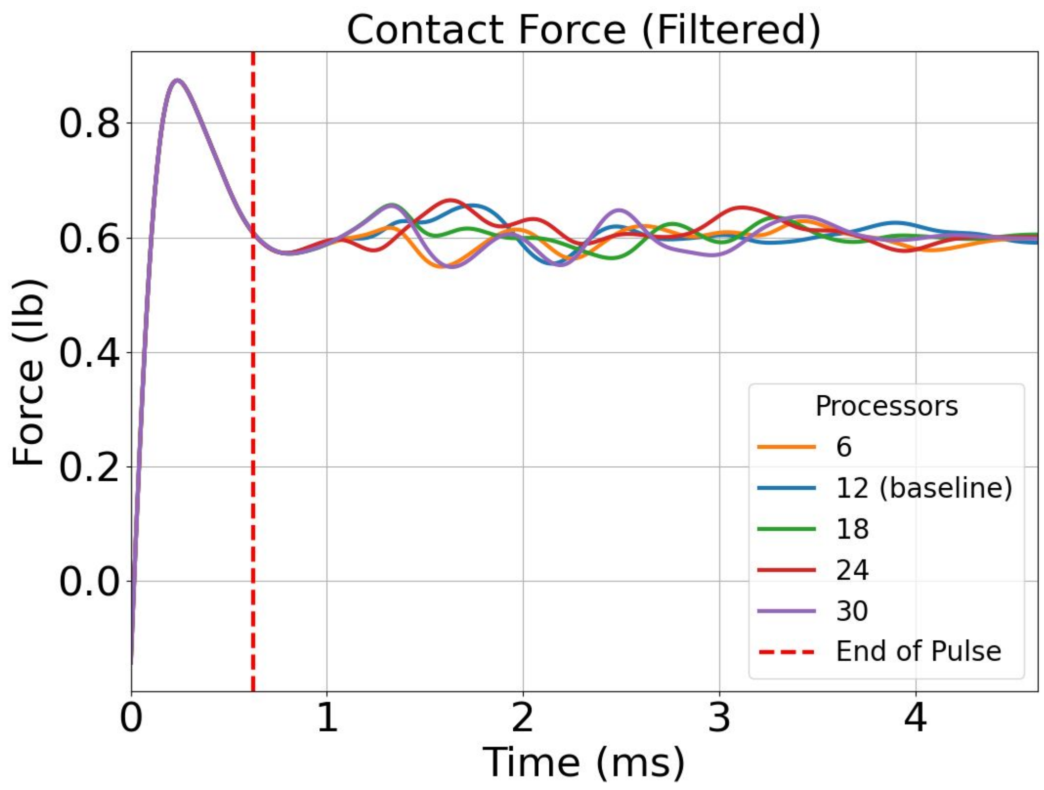




- Similar to momentum balance, overall rotation trend is similar but different in damping and amplitude to idealized model
- Less rotation allowed for very coarse mesh density (potentially a lock-up)
- More rotation allowed as element becomes finer
- Contact force does not converge

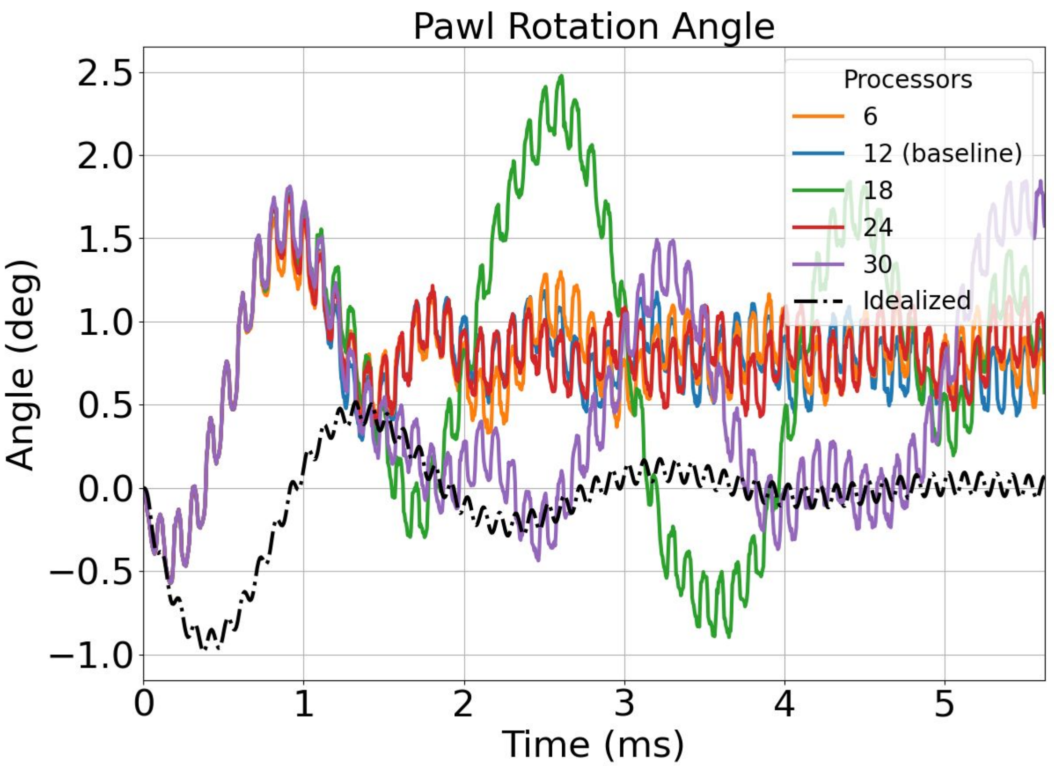
Number of Processors Used – Pin-Pawl (Haversine Shock)

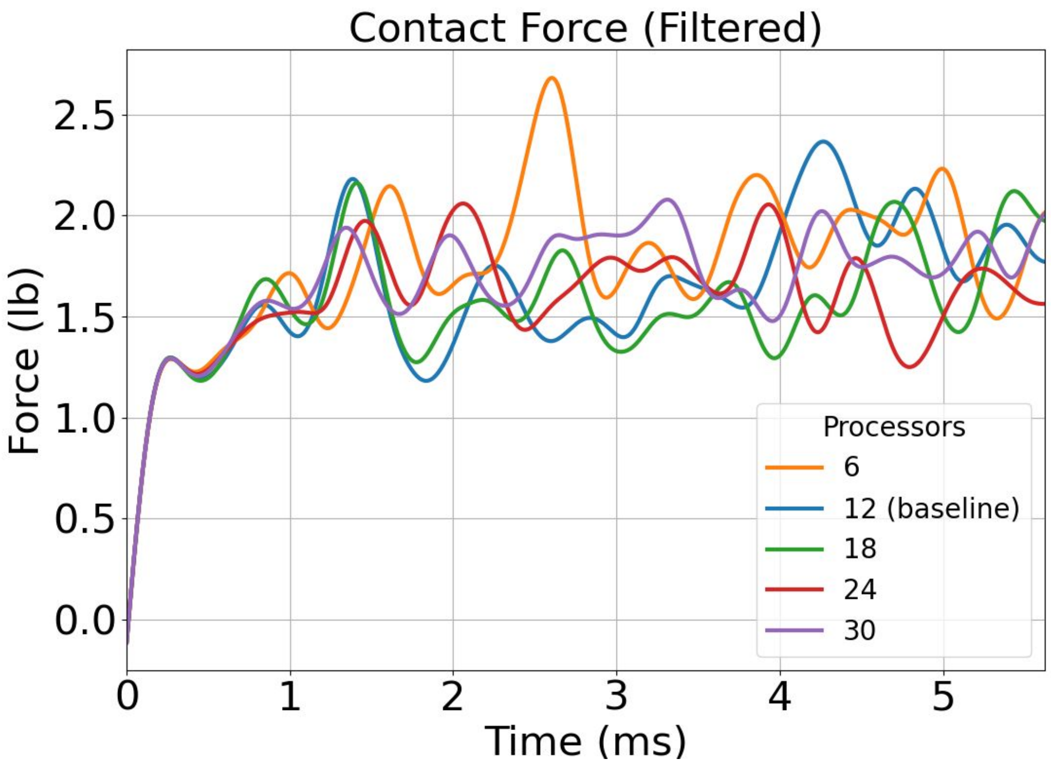




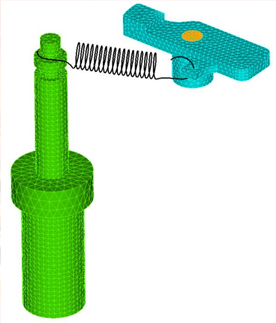
- Very small difference in rotation and larger difference in contact force after less than 1 ms
- Less sensitive to processor count

Number of Processors Used – Pin-Pawl (Sinusoidal Vibration)

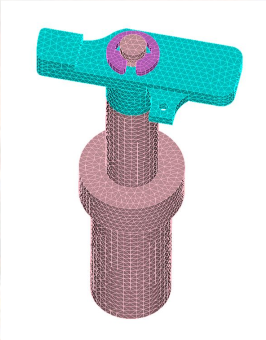




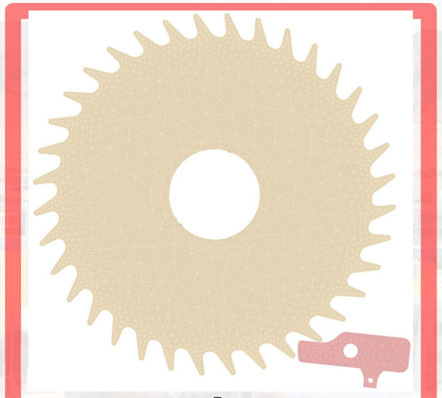
- Similar to haversine, results diverge after less than 1 ms
- Difference is much larger than that of haversine shock
- Sensitive to processor count



Pin-spring-pawl



Pin-pawl

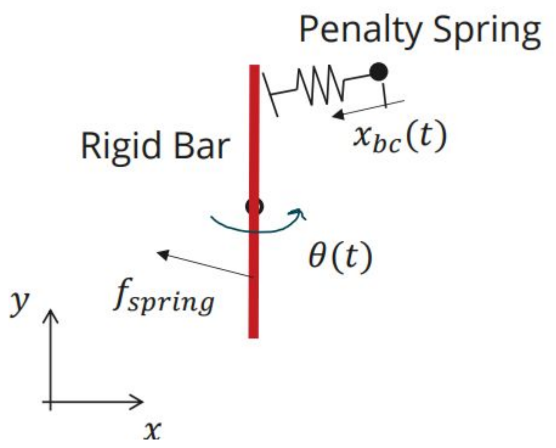


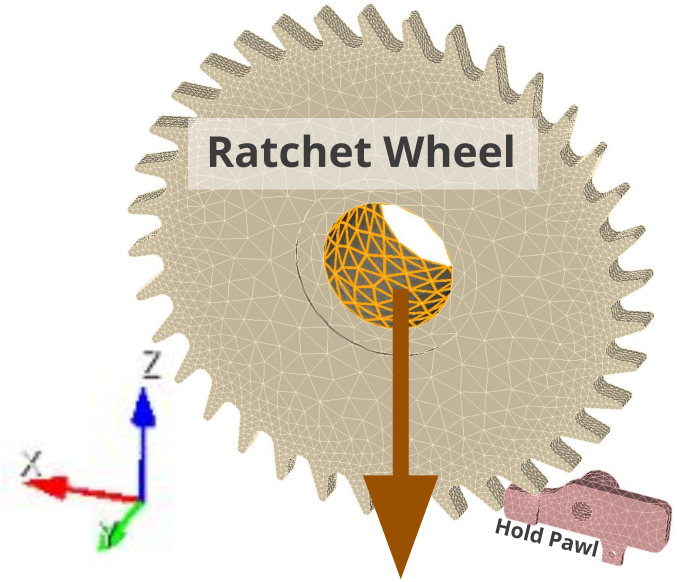
Pawl-gear

Submodel – Pawl-gear

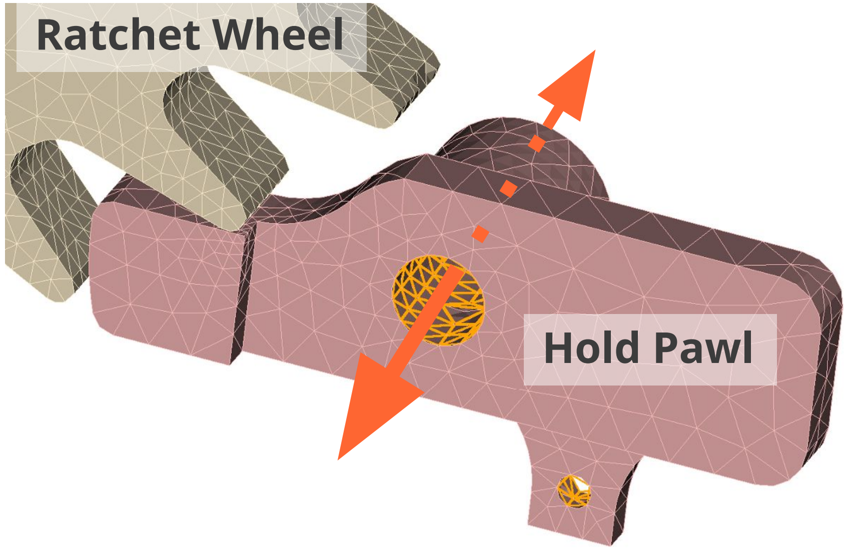
Pawl-Gear Submodel

- **Boundary Conditions**
  - Ratchet wheel is pushed and contacts hold pawl
  - Pseudo spring force rotates pawl into ratchet wheel
- **Quantity of Interest**
  - Part rotation of the hold pawl over time

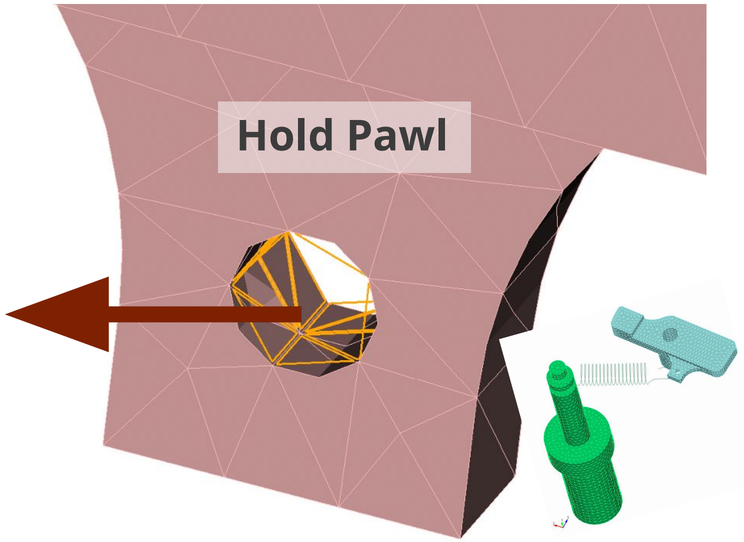




Prescribed displacement in Z direction (shock or vibration)

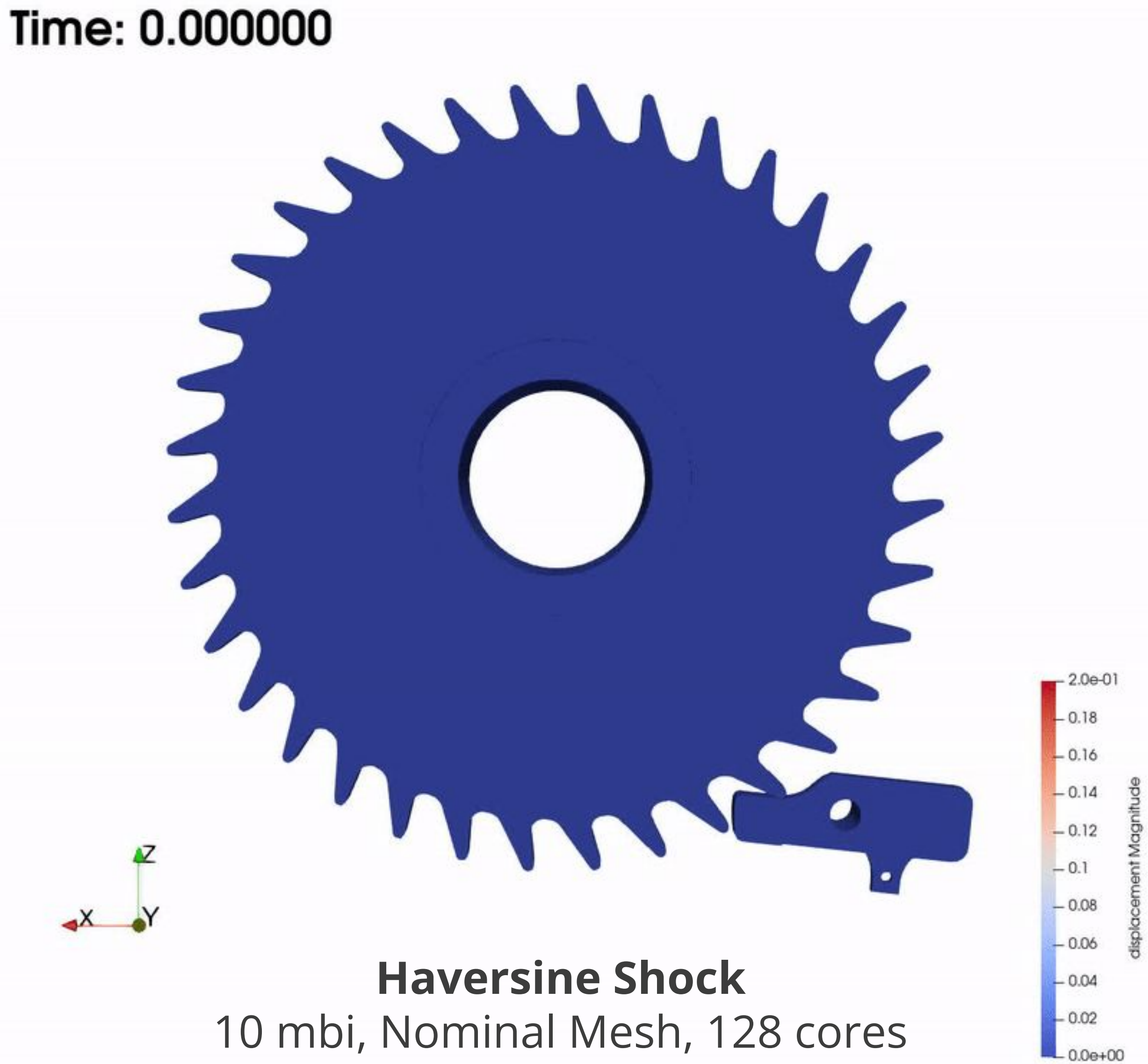


Pawl is fixed in radial and axial direction

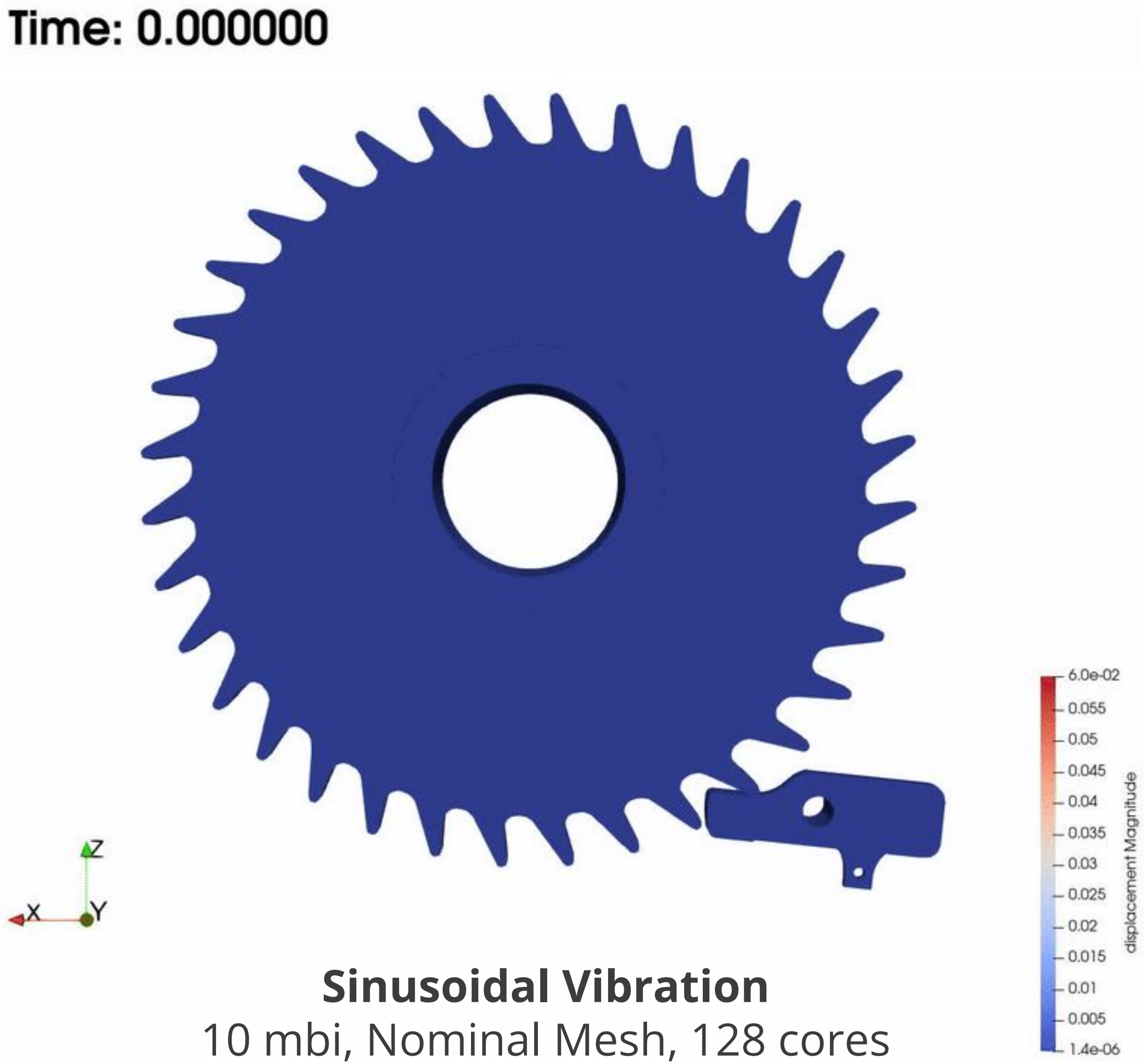


"Pseudo spring force" along pawl spring direction

Pawl-Gear Submodel

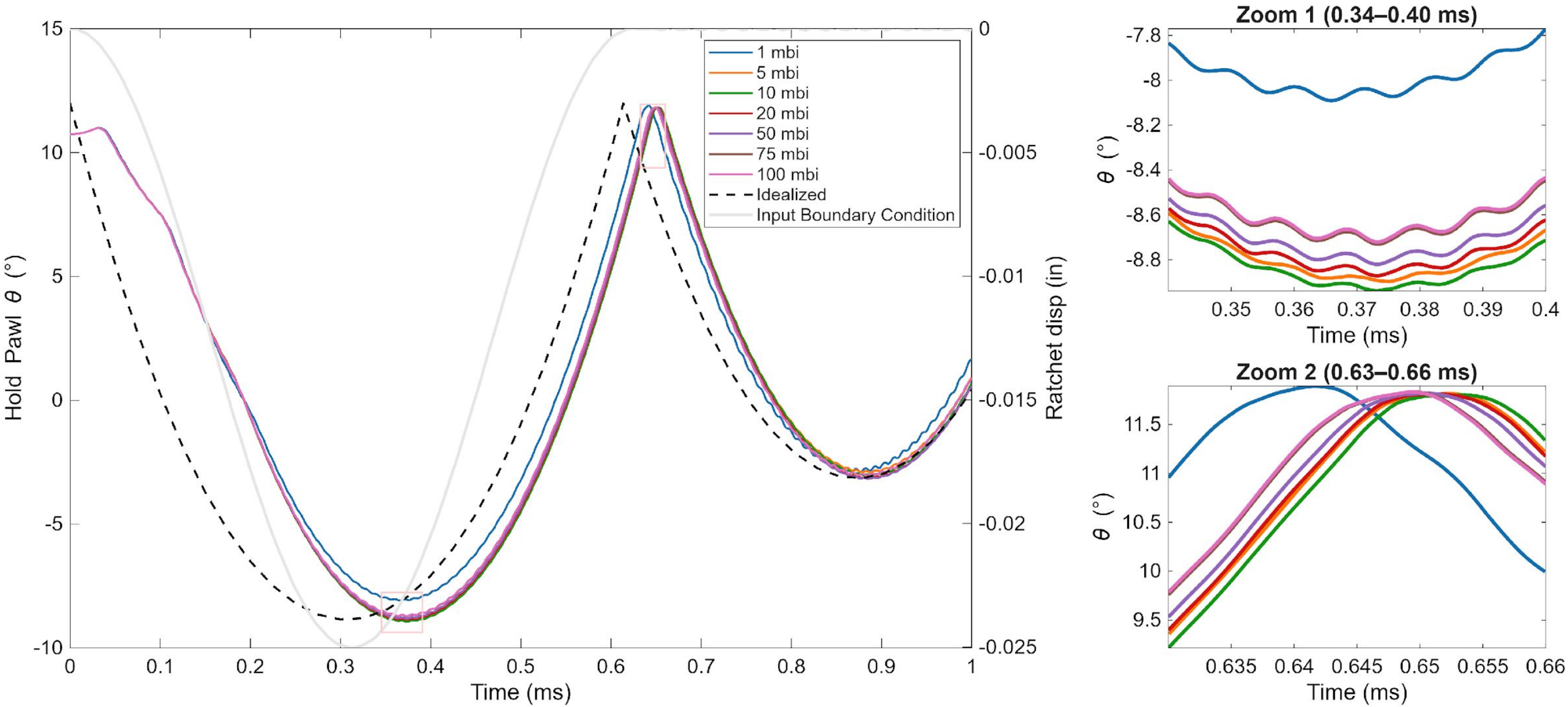


Haversine Shock
10 mbi, Nominal Mesh, 128 cores



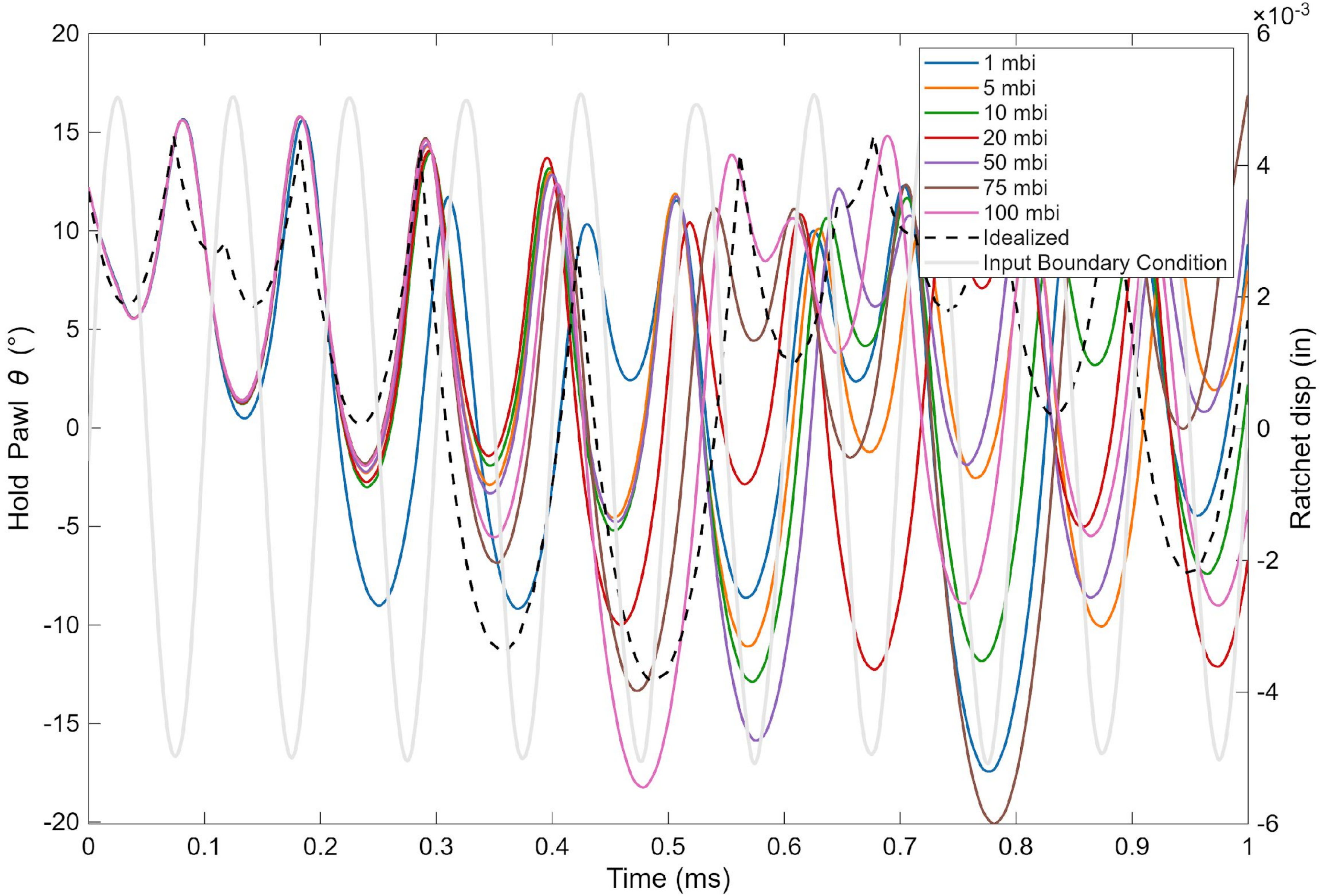
Sinusoidal Vibration
10 mbi, Nominal Mesh, 128 cores

Momentum Balance Iteration – Pawl-Gear (Haversine Shoc



Haversine shock settings: 0.025 inch amplitude, 0.5 lbf pseudo force, 100% mesh density, 128 cores

Momentum Balance Iteration – Pawl-Gear (Sinusoidal Vibration)

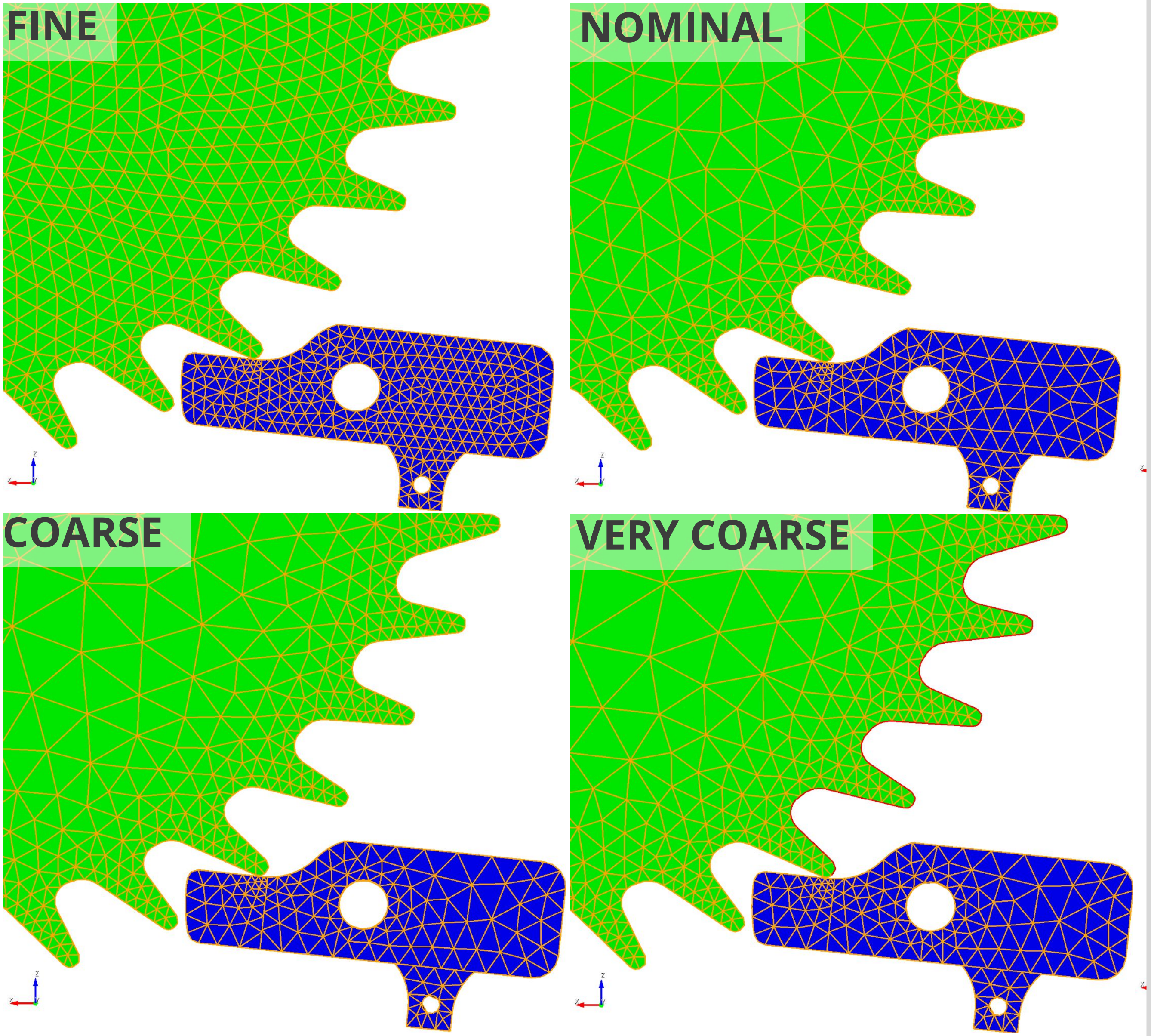


Sinusoidal vibration settings: 10 kHz, 0.005 inch amplitude, 13 lbf pseudo force, 100% mesh density, 128 cores

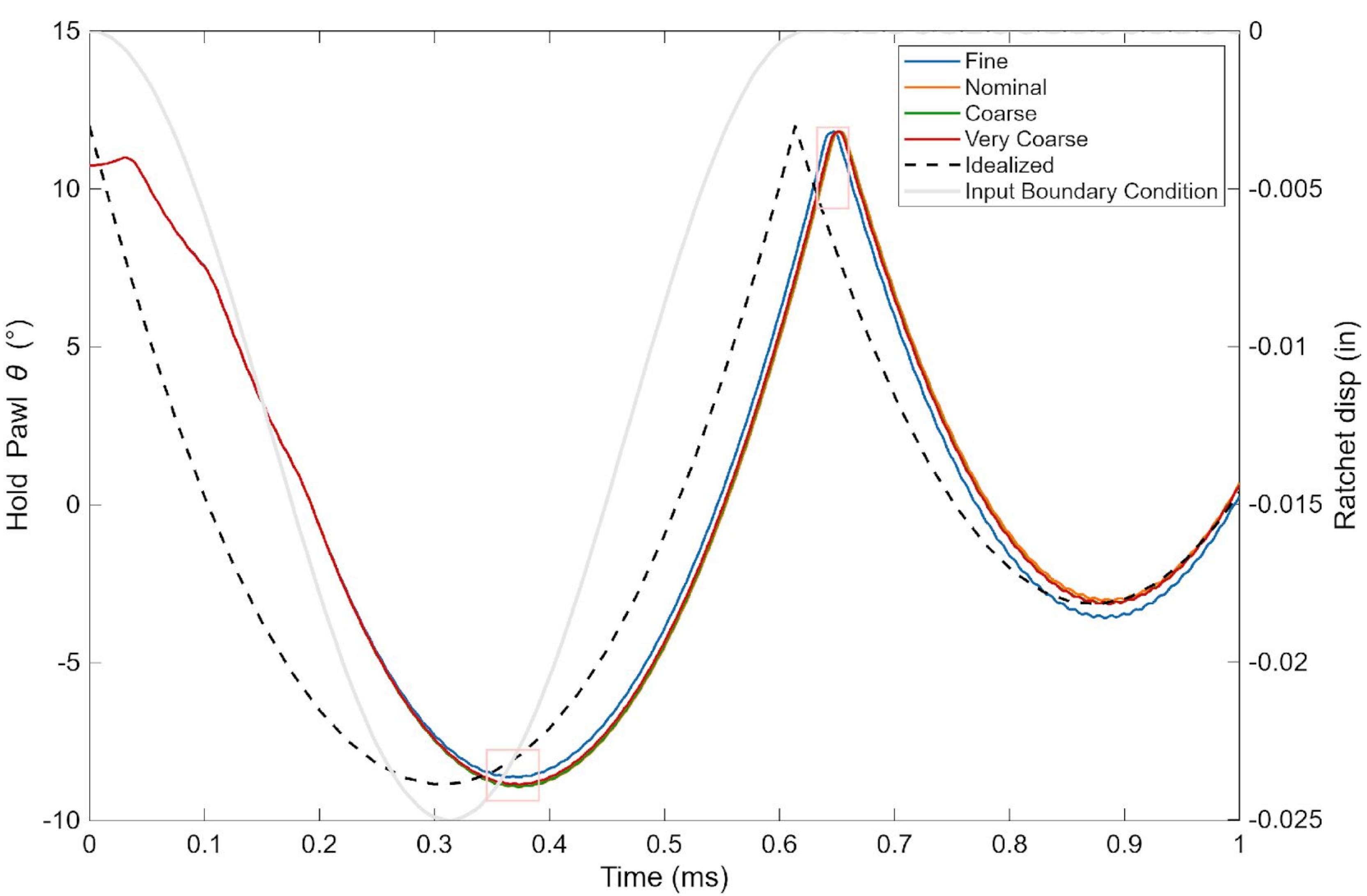
Mesh Density – Pawl-Gear

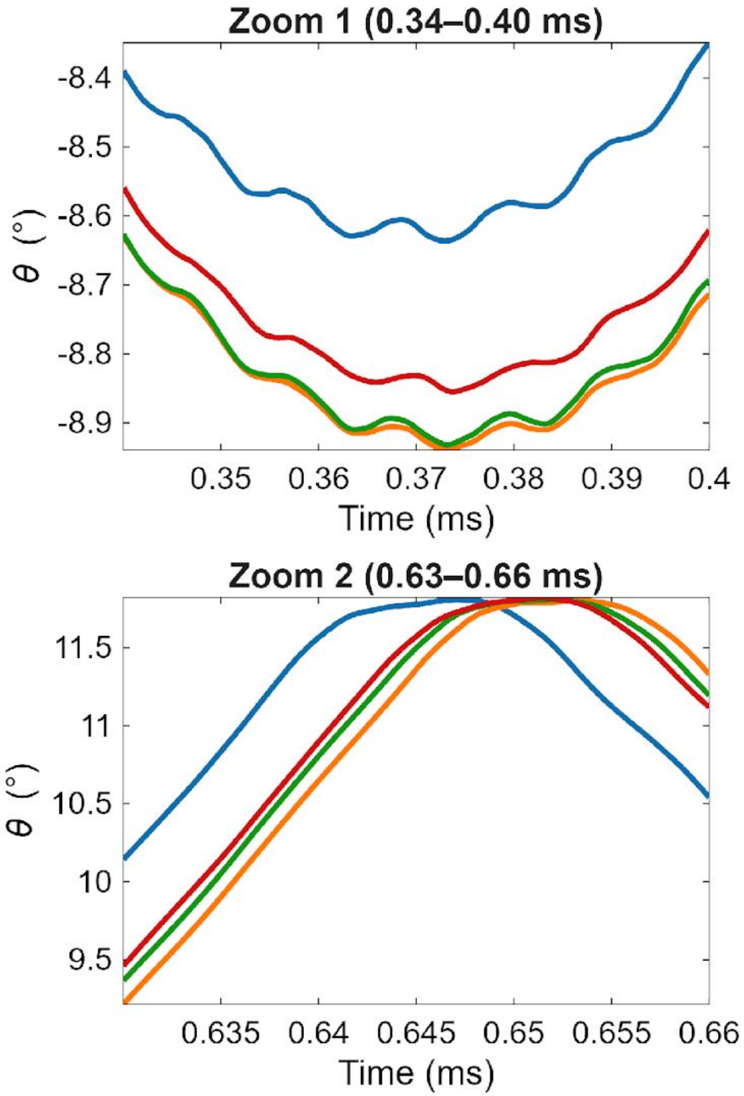
Element Count

FINE: 89705
COARSE: 32736
NOMINAL: 36467
VERY COARSE: 32106



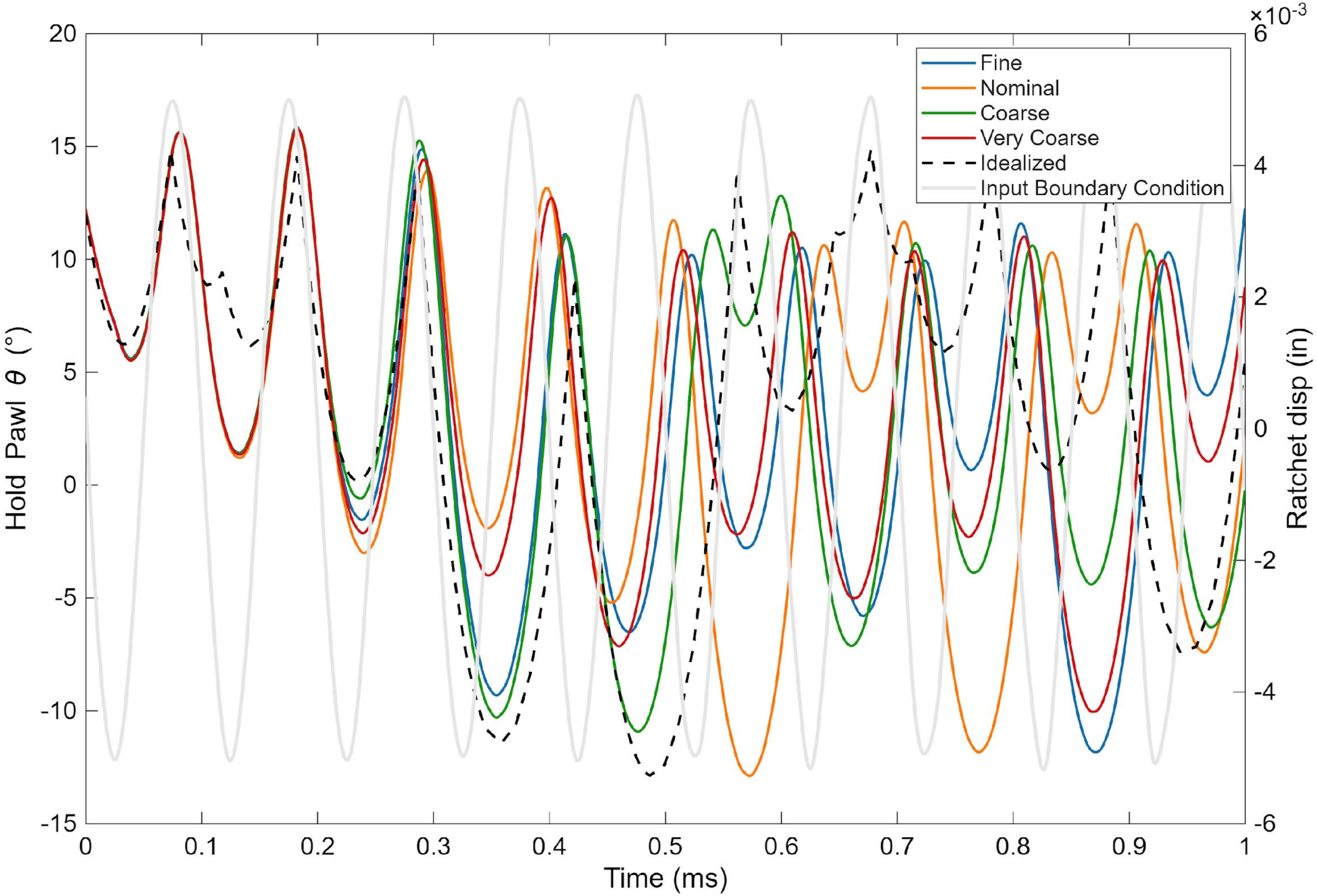
Mesh Density – Pawl-Gear (Haversine Shock)





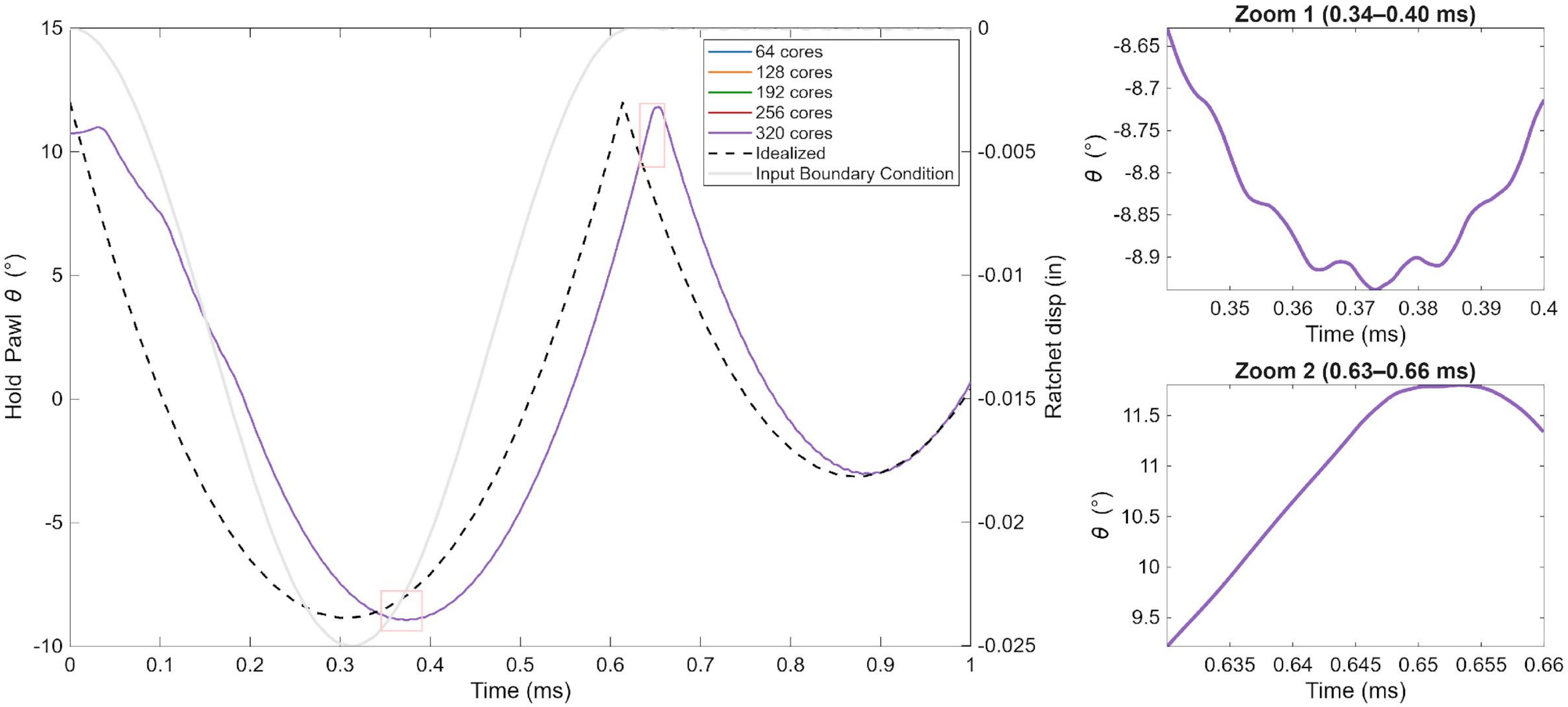
Haversine shock settings: 0.025 inch amplitude, 0.5 lbf pseudo force, 10 mbi, 128 cores

Mesh Density – Pawl-Gear (Sinusoidal Vibration)



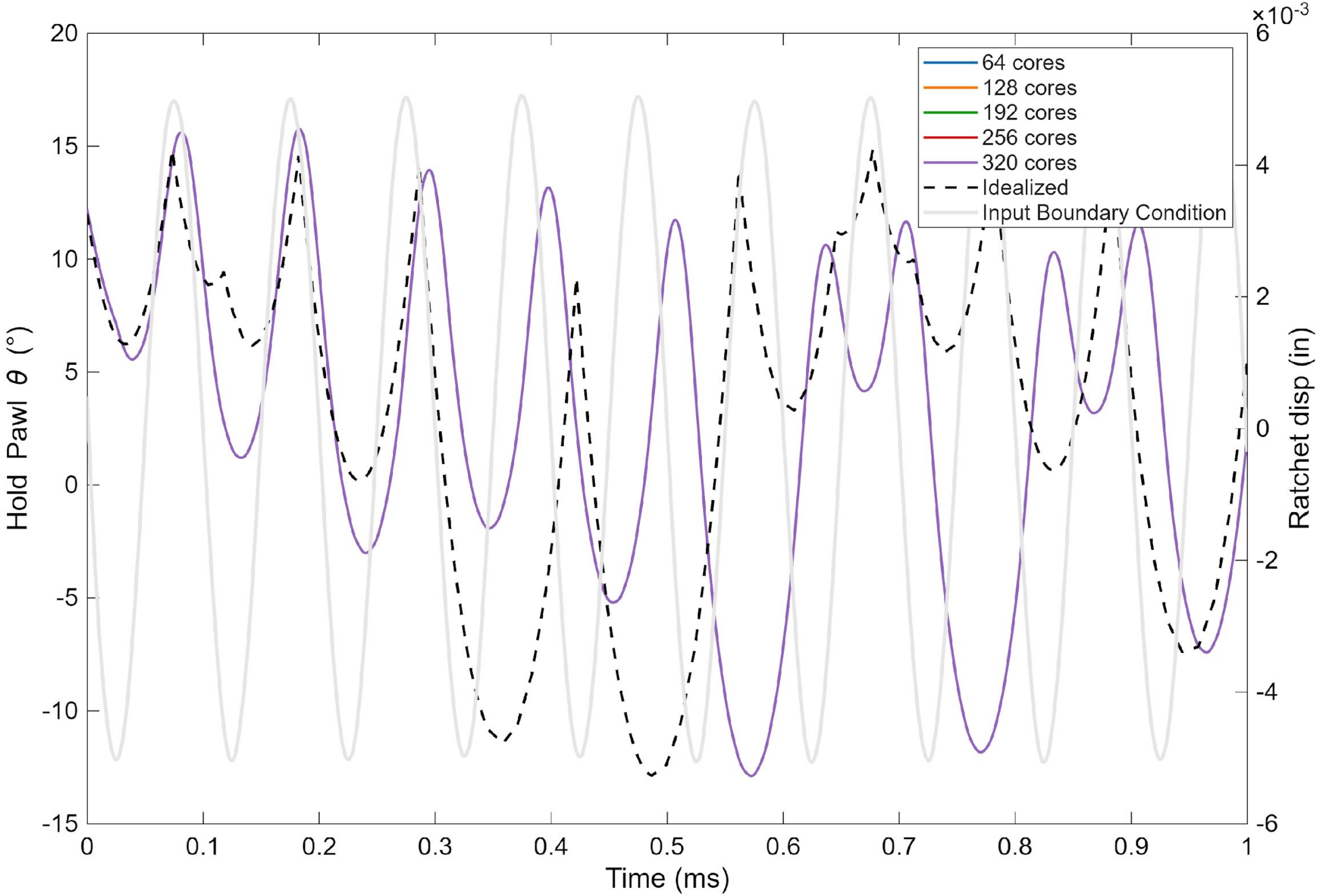
Sinusoidal vibration settings: 10 kHz, 0.005 inch amplitude, 13 lbf pseudo force, 10 mbi, 128 cores

Processor Count – Pawl-Gear (Haversine Shock)



Haversine shock settings: 0.025 inch amplitude, 0.5 lbf pseudo force, 100% mesh density, 10 mbi

Processor Count – Pawl-Gear (Sinusoidal Vibration)



Sinusoidal vibration settings: 10 kHz, 0.005 inch amplitude, 13 lbf pseudo force, 100% mesh density, 10 mbi

Summary of Results

- Sensitivity of submodels to each parameter in each environment

	Pin-Spring-Pawl		Pin-Pawl		Pawl-Gear	
	Shock	Vibration	Shock	Vibration	Shock	Vibration
Momentum Balance Iteration						
Mesh Density						
Processor Count						

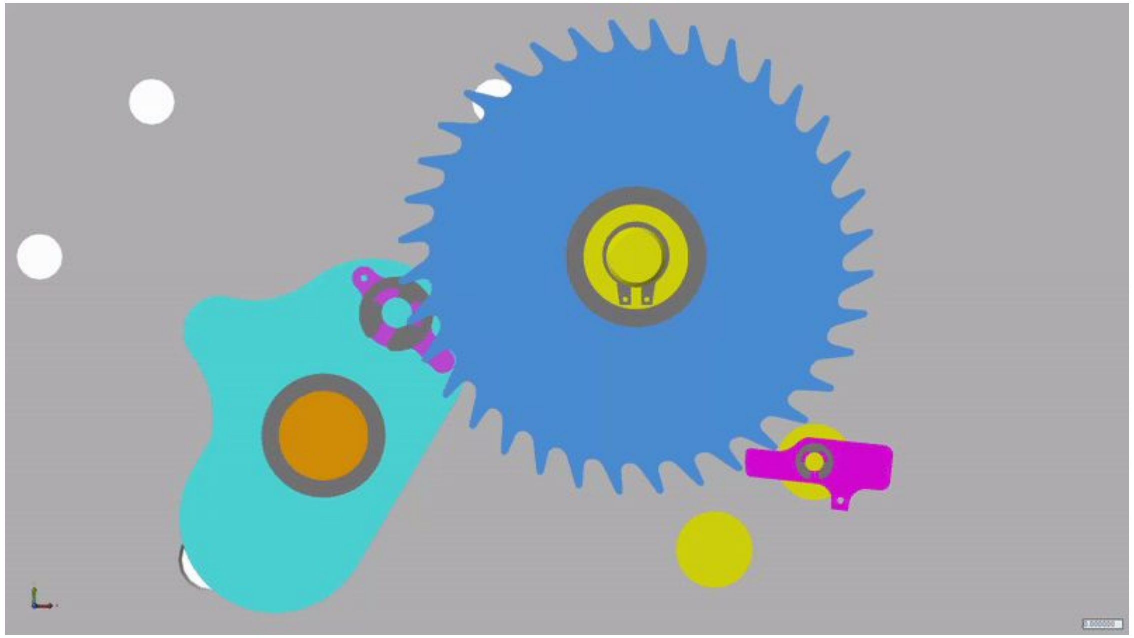
= Insensitive = Sensitive

Conclusion

- The parametric study of the non-physical parameters including momentum balance iteration, mesh density and number of processors used has revealed sensitive nature of the FE model even at the sub-model level of a ratcheting mechanism
- Results further affirms the complexity of a ratcheting mechanism and the consideration required to model such mechanism with accuracy

Future Work

- Combine the sub-models and study how the effects of the non-physical parameters change
- Study other non-physical parameters
- Perform similar study on the drive pawl model and extend study to assembly level.



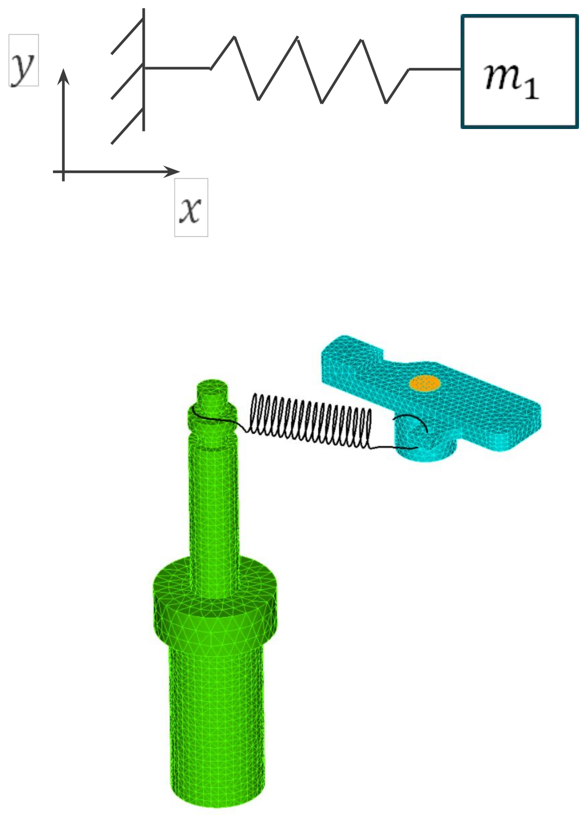
Acknowledgements

This research was conducted at the 2025 Nonlinear Mechanics and Dynamics Research Institute hosted by Sandia National Laboratories and the University of New Mexico.

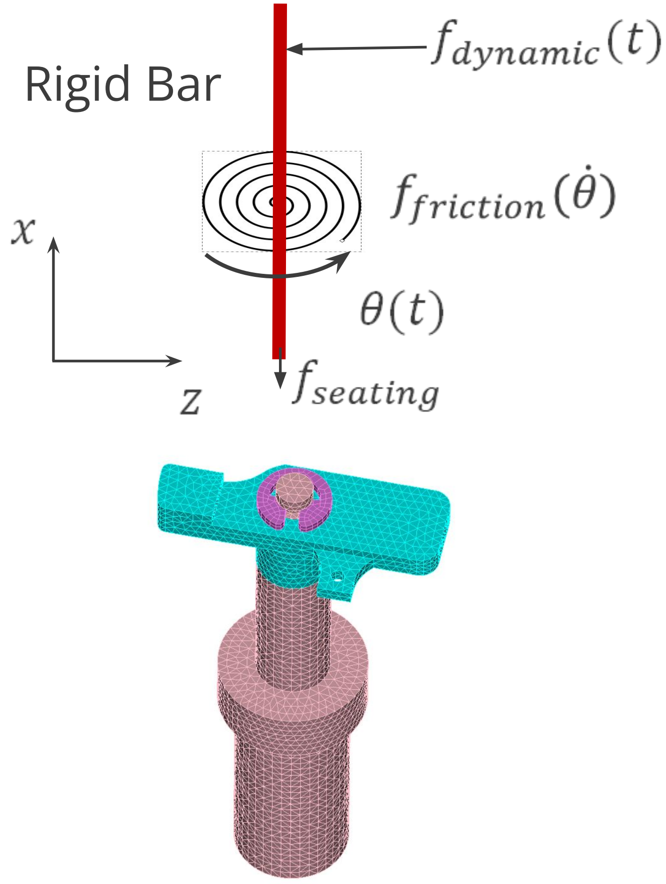
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

Idealized Model

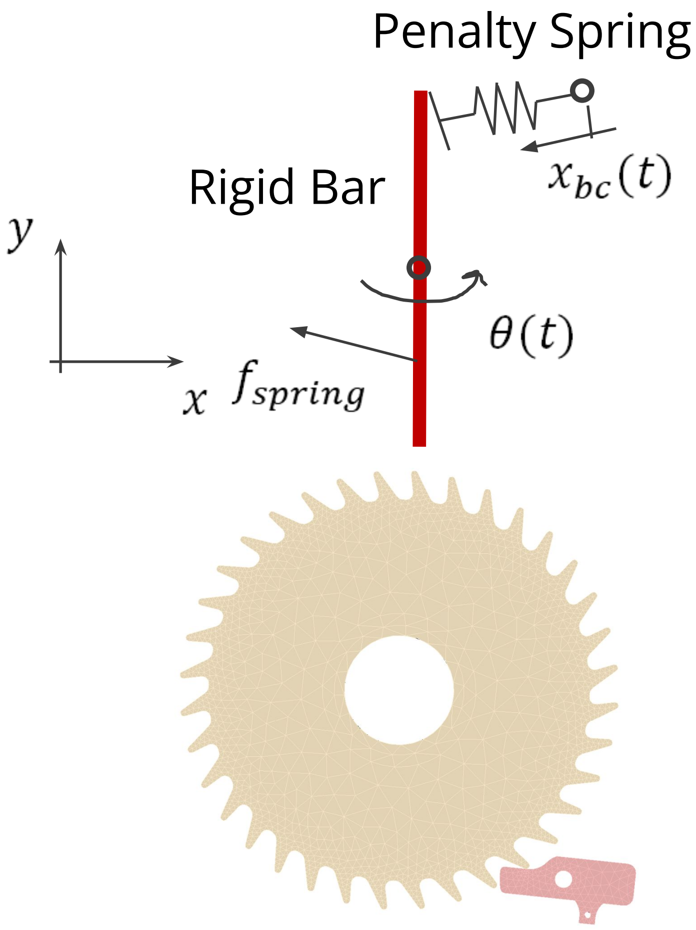
- **A simplified approximation of a system for quick and easy analysis**



Pin-spring-pawl



Pin-pawl

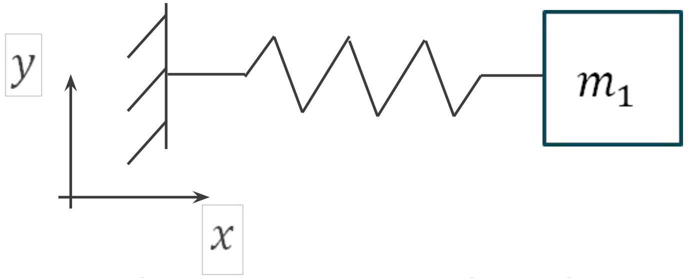


Pawl-gear

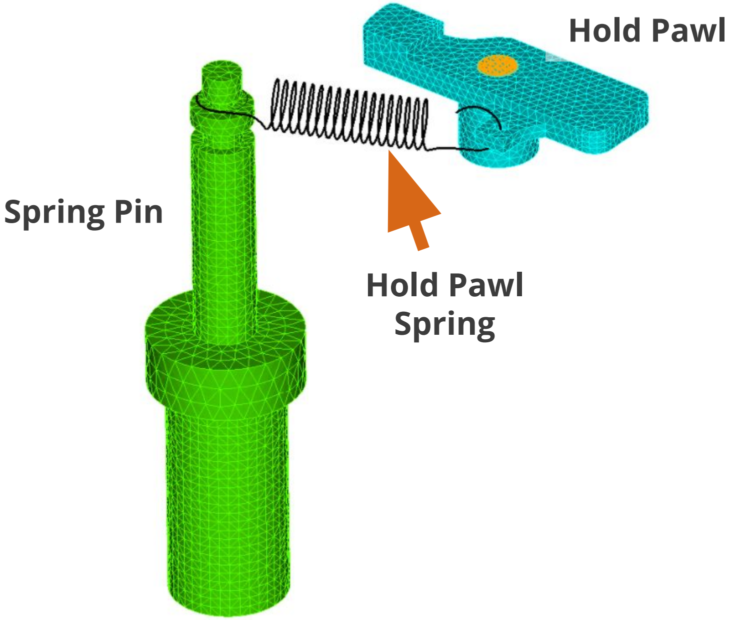
Pin-Spring-Pawl Submodel

- **Boundary Conditions**
  - Base of Pin is fixed in all degree's of freedom
  - Center of pawl is displaced in the axial direction of the spring
- **QOIs**
  - Contact force on Hold Pawl and Spring Pin

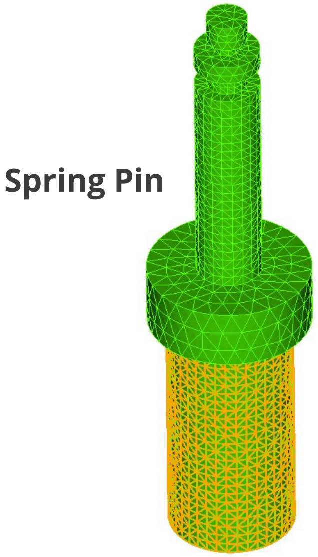
Idealized Model:



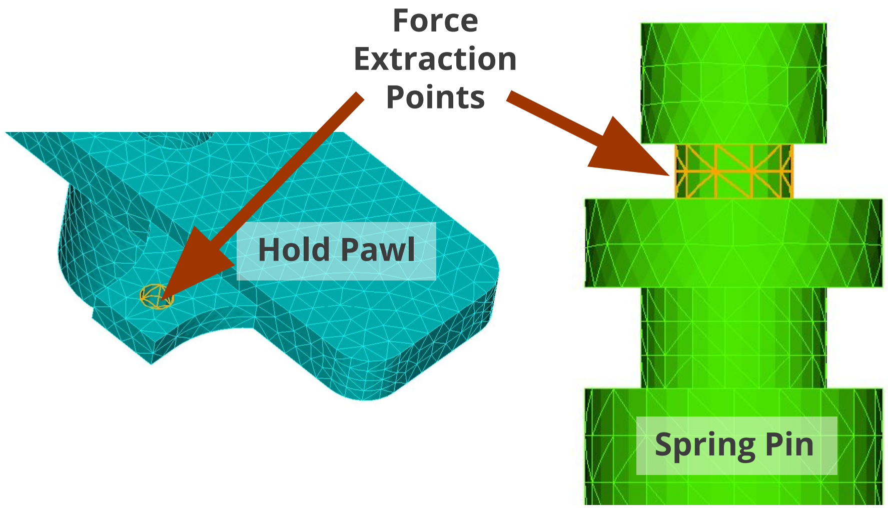
Where m_1 is equal to the mass of the Hold Pawl Spring



Prescribed displacement to the Hold Pawl in the axial direction of the spring



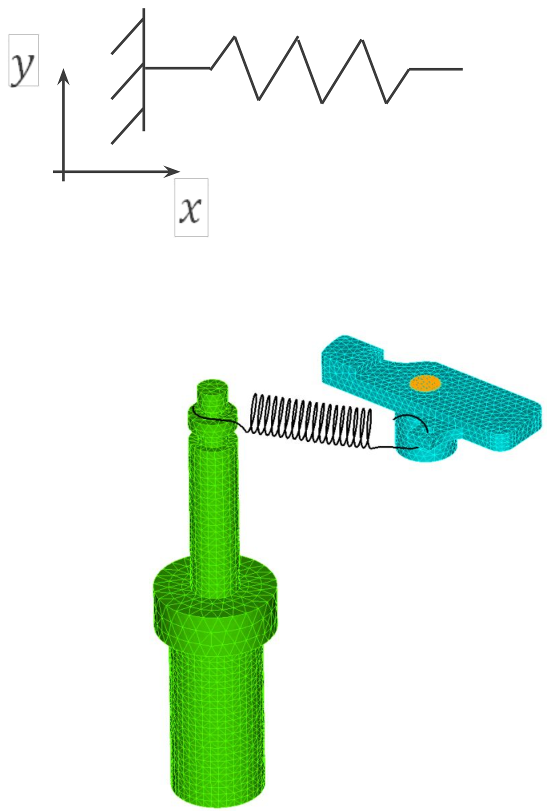
Base of Pin is fixed in all DOF's.



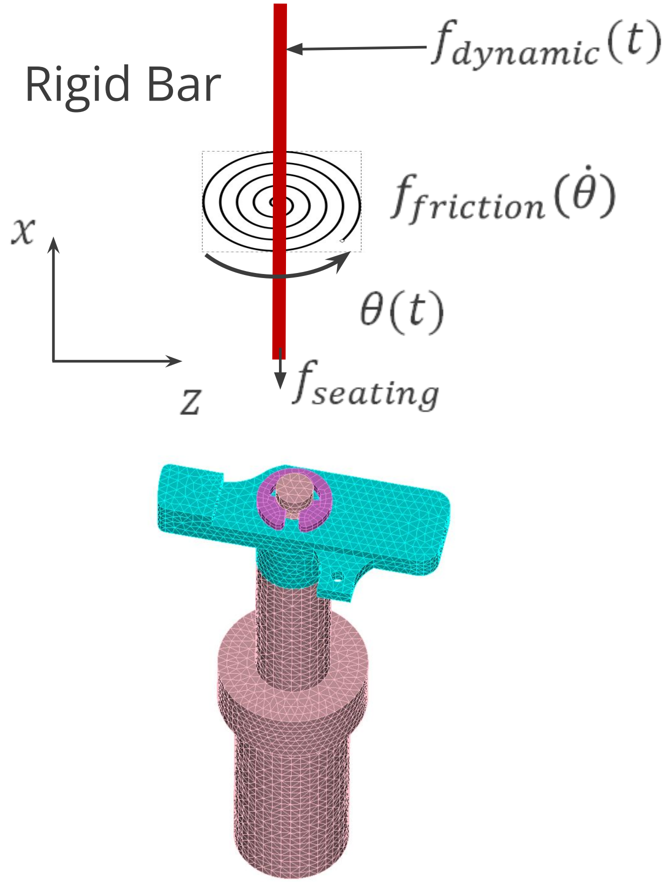
Force Extracted Where Spring Interacts with the Pin and Pawl

Idealized Model

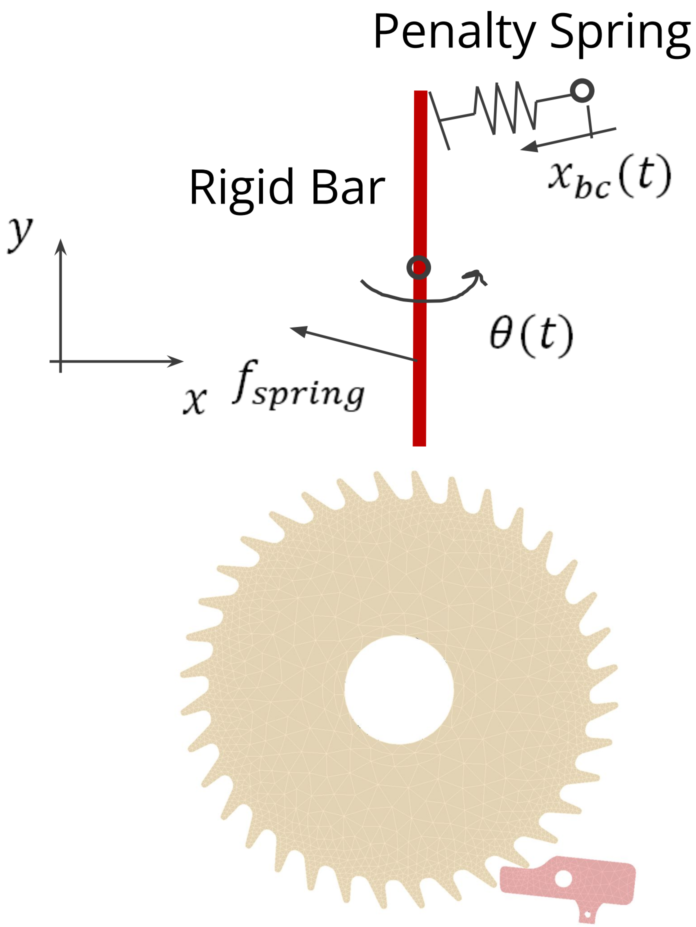
- **A simplified approximation of a system for quick and easy analysis**



Pin-spring-pawl



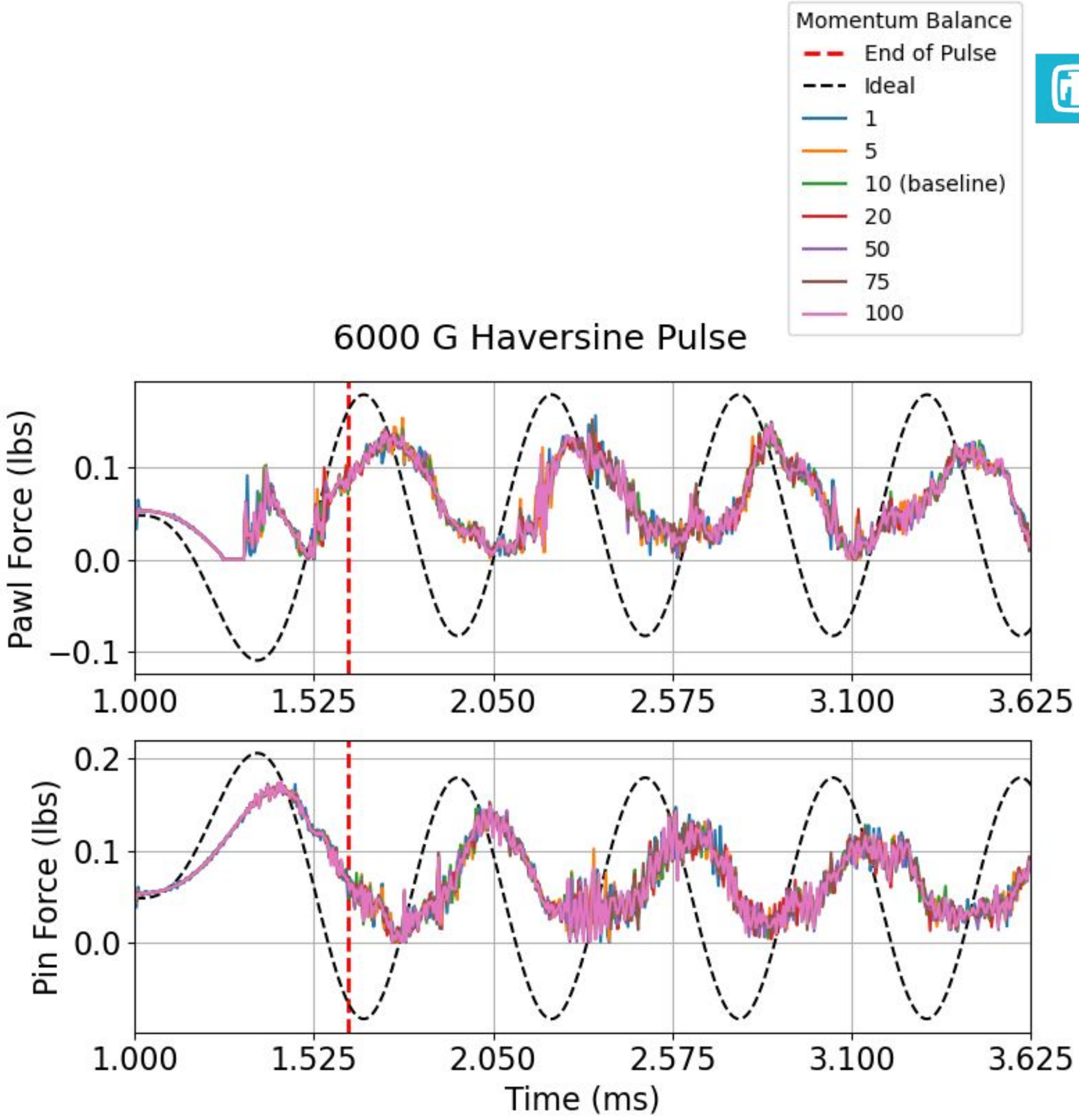
Pin-pawl



Pawl-gear

Note for IR Reviewer

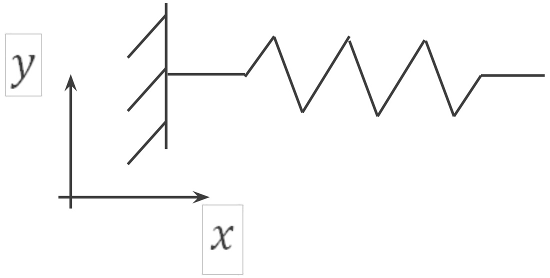
My idealized model isn't quite working as planned. I plan on trying to remake the graphs in this subsection (slides 15-28) to account for the new idealized model. The results will look similar to the figure on this slide. I'm attempting to model the same system with the same environments, just different technique. I'm trying to make the FEM data (solid lines) match the ideal model (black dashed line), so you should have a good idea as to what the new plots will look like.

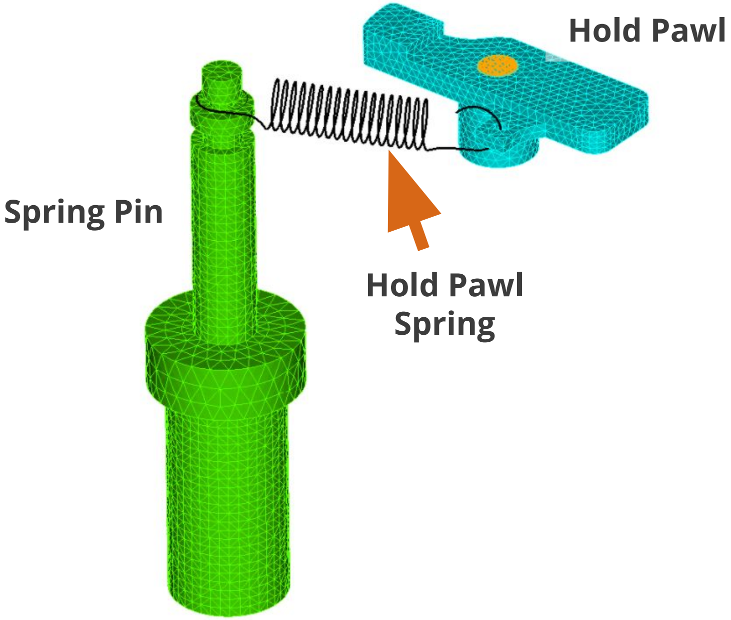


Pin-Spring-Pawl Submodel

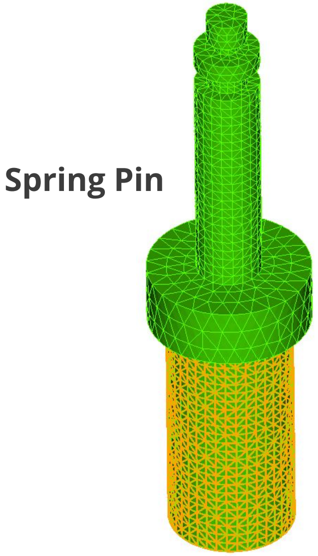
- **Boundary Conditions**
  - Base of Pin is fixed in all degree's of freedom
  - Center of pawl is displaced in the axial direction of the spring
- **QOIs**
  - Contact force on Hold Pawl and Spring Pin

Idealized Model:

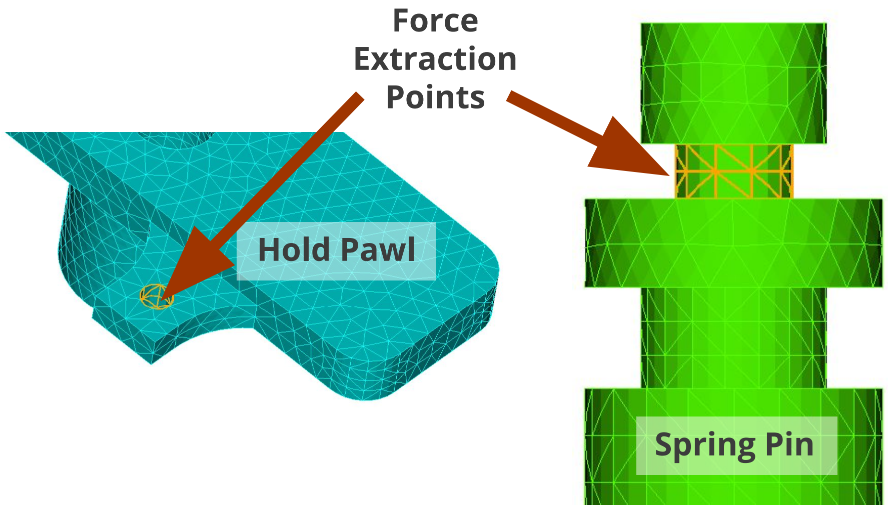




Prescribed displacement to the Hold Pawl in the axial direction of the spring

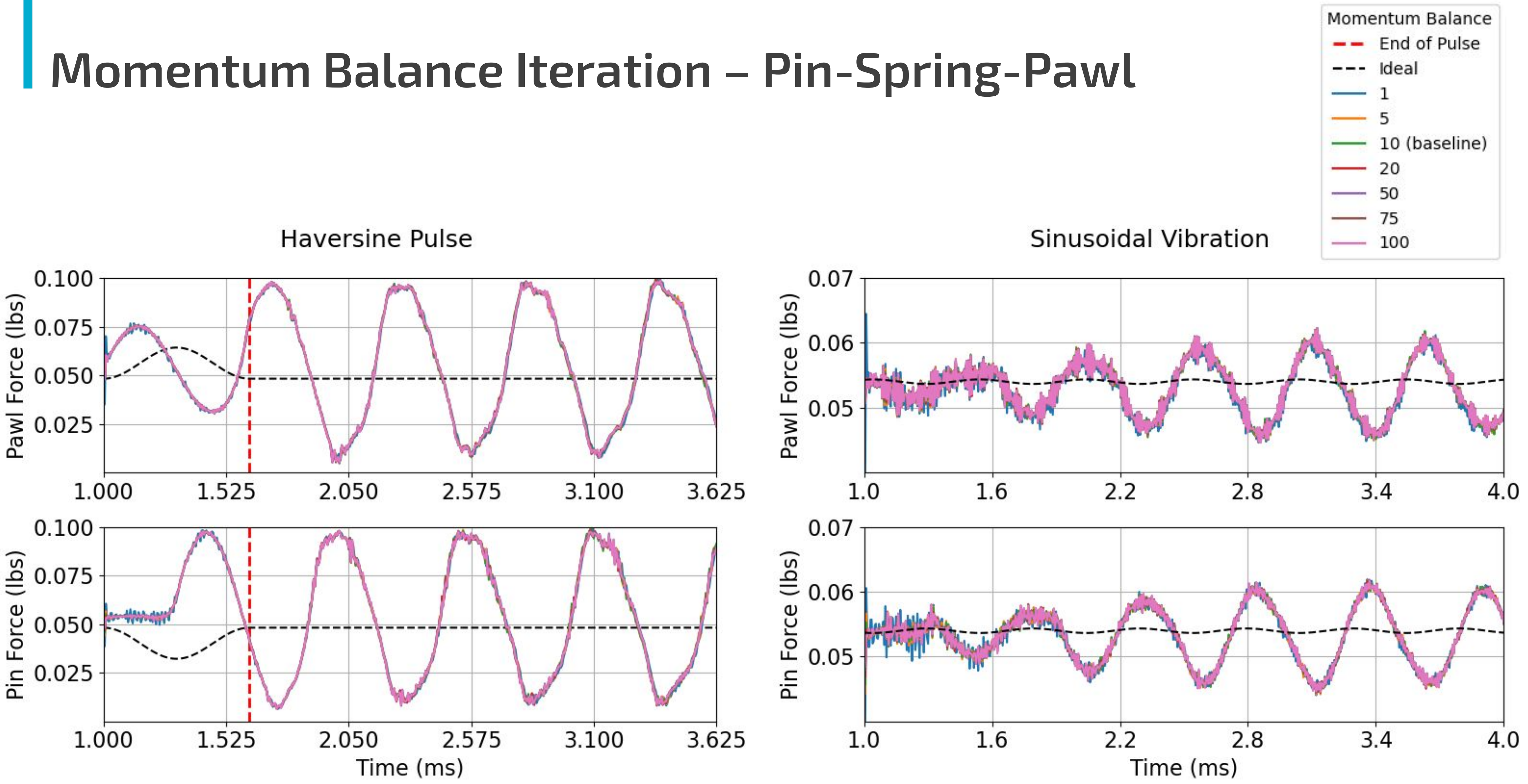


Base of Pin is fixed in all DOF's.



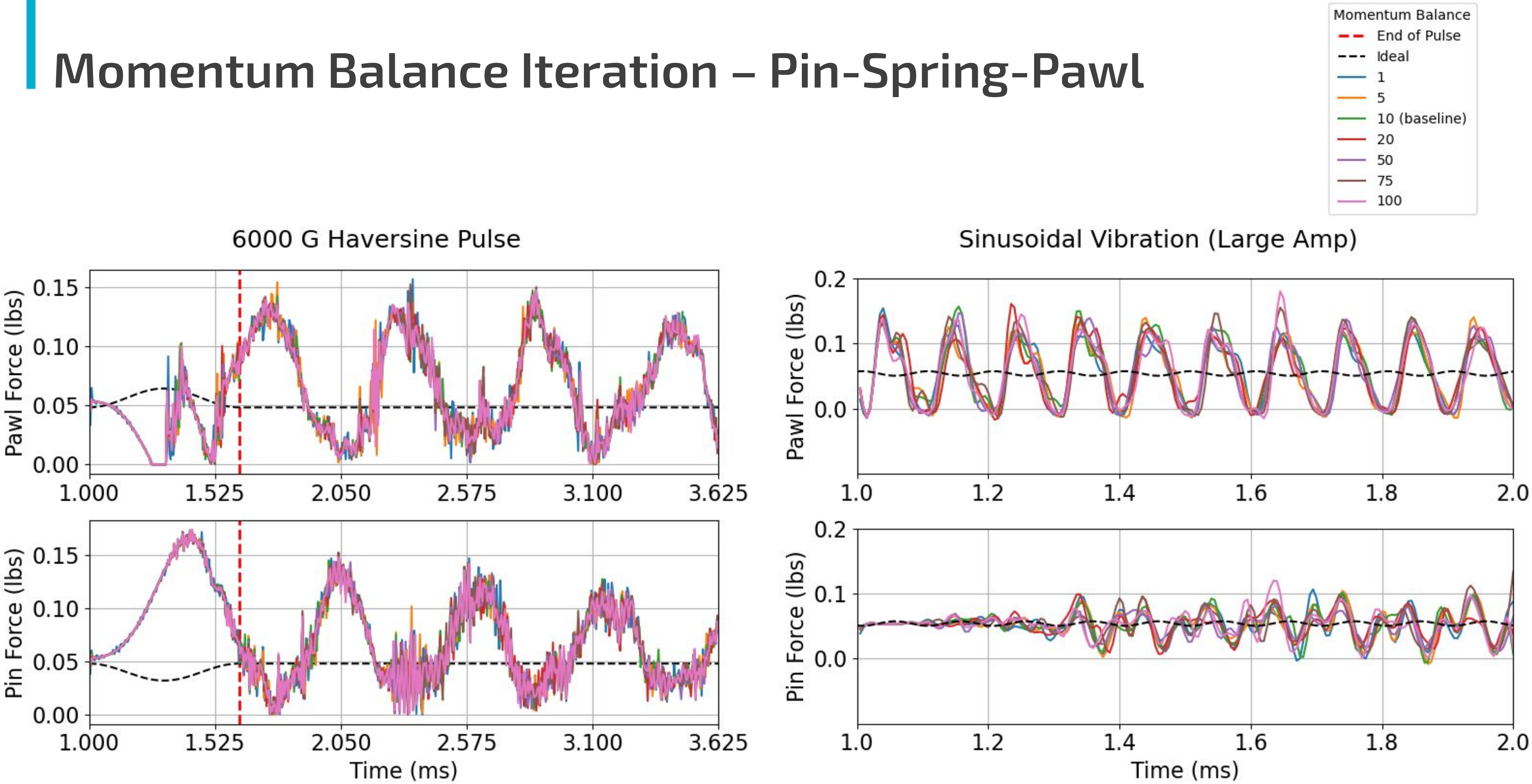
Force Extracted Where Spring Interacts with the Pin and Pawl

Momentum Balance Iteration – Pin-Spring-Pawl



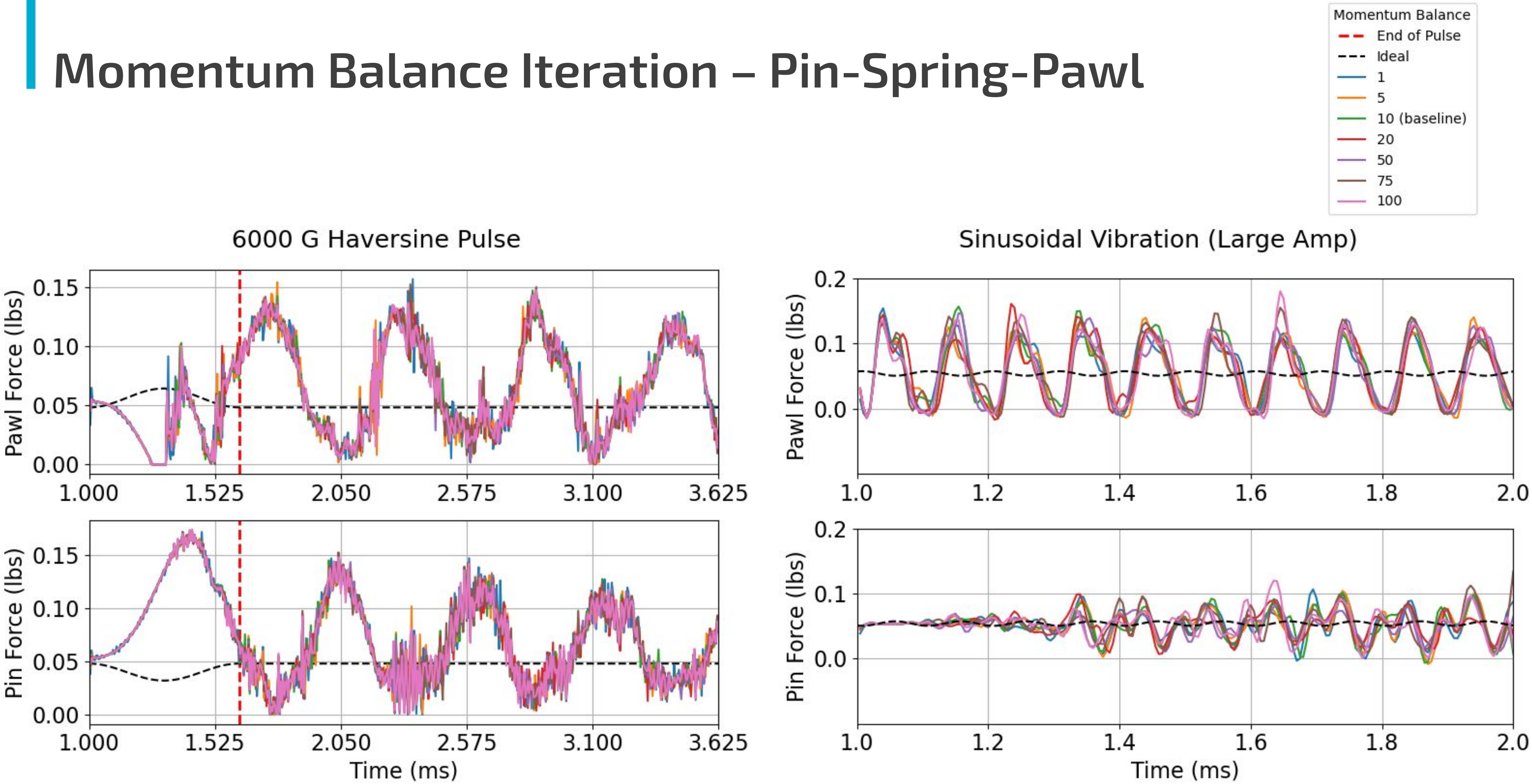
- Submodel is not sensitive to the number of momentum balance iterations used during analysis
- Ideal model needs adjustments to make accurate predictions of dynamics

Momentum Balance Iteration – Pin-Spring-Pawl



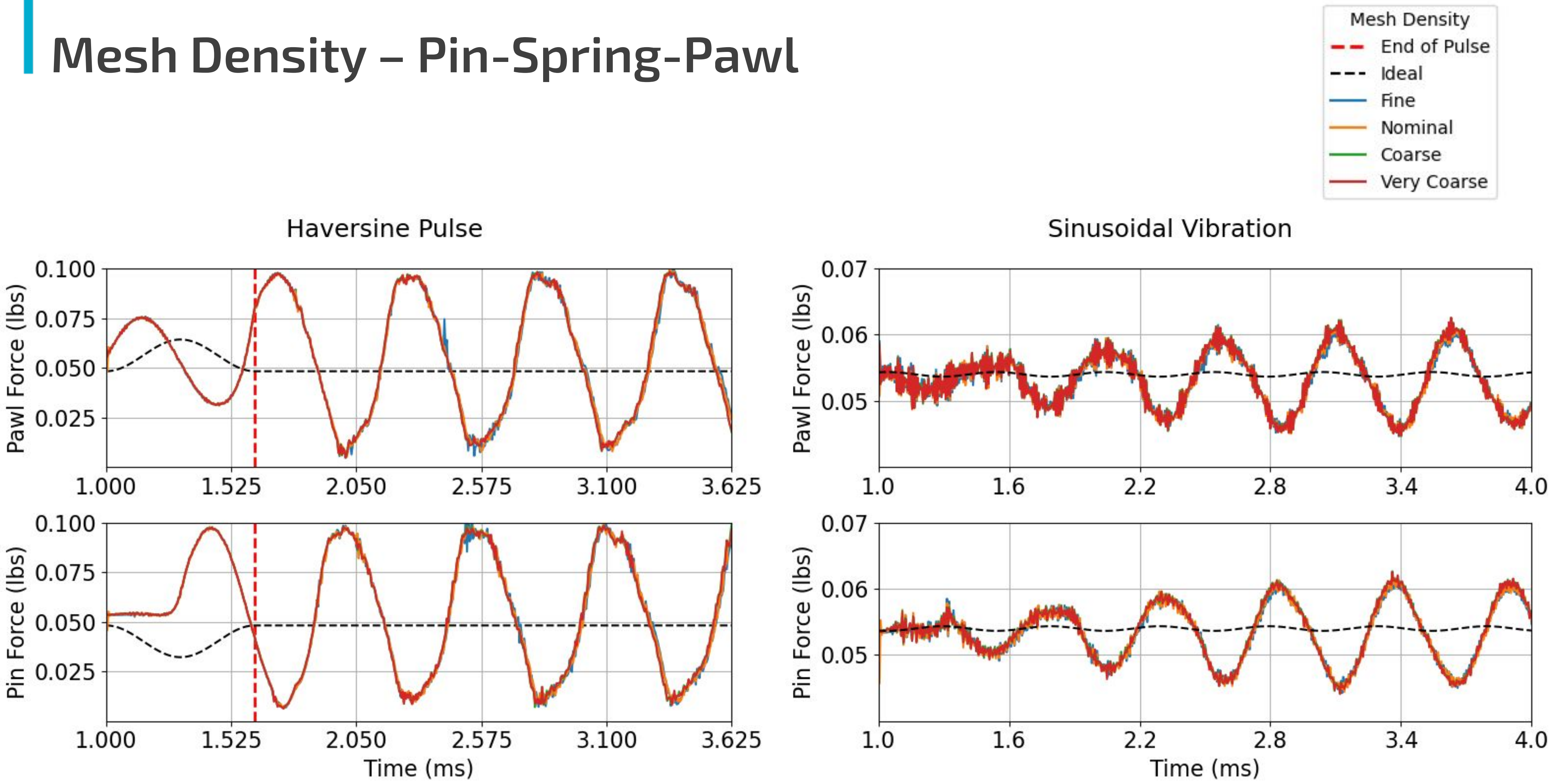
- 6000 g drop test simulation / Order of magnitude amplitude increase
- Even at larger amplitudes the FE model converges to the same solution

Momentum Balance Iteration – Pin-Spring-Pawl



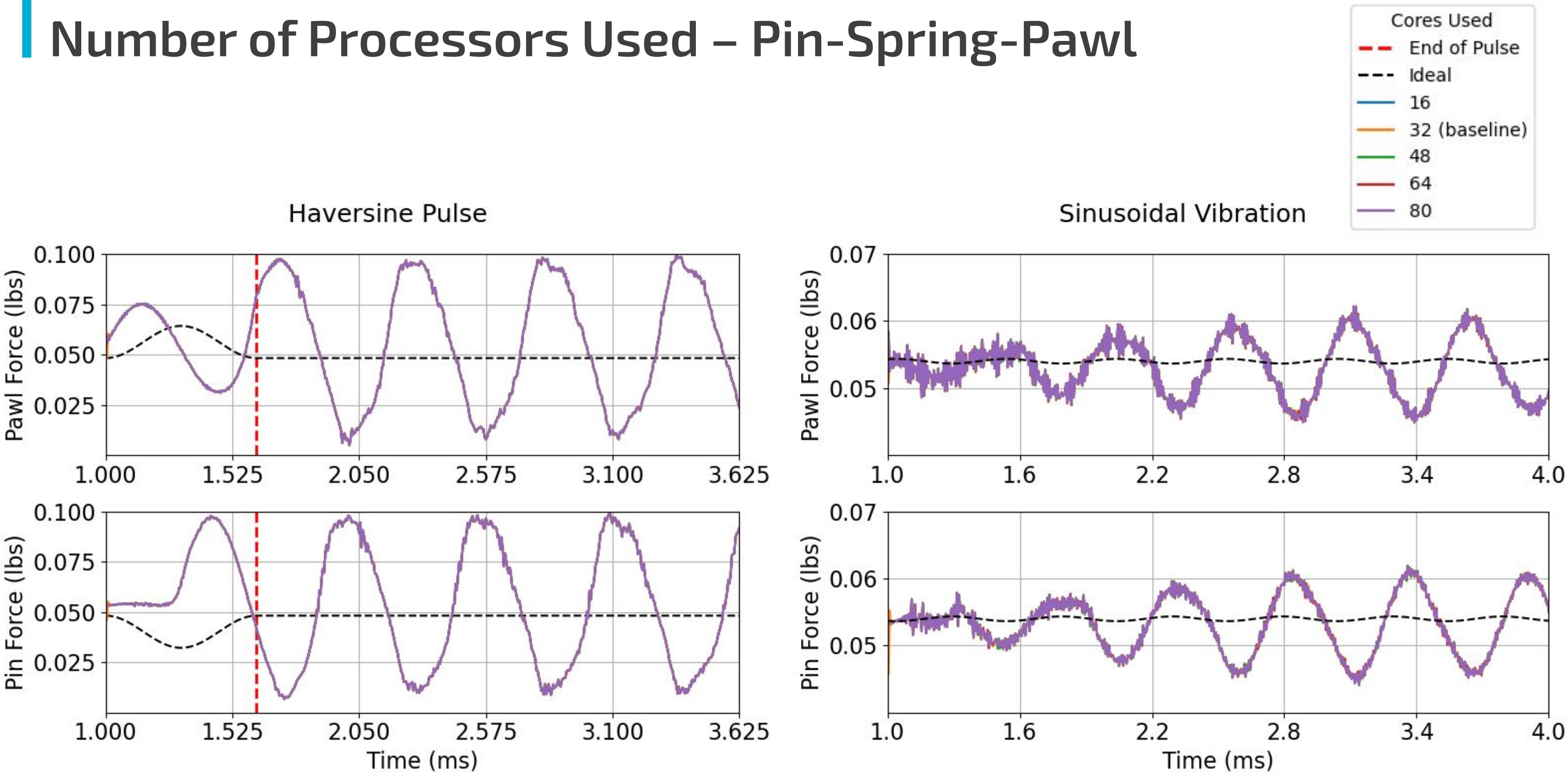
- 6000 g drop test simulation / Order of magnitude amplitude increase
- Even at larger amplitudes the model converges to the same solution

Mesh Density – Pin-Spring-Pawl



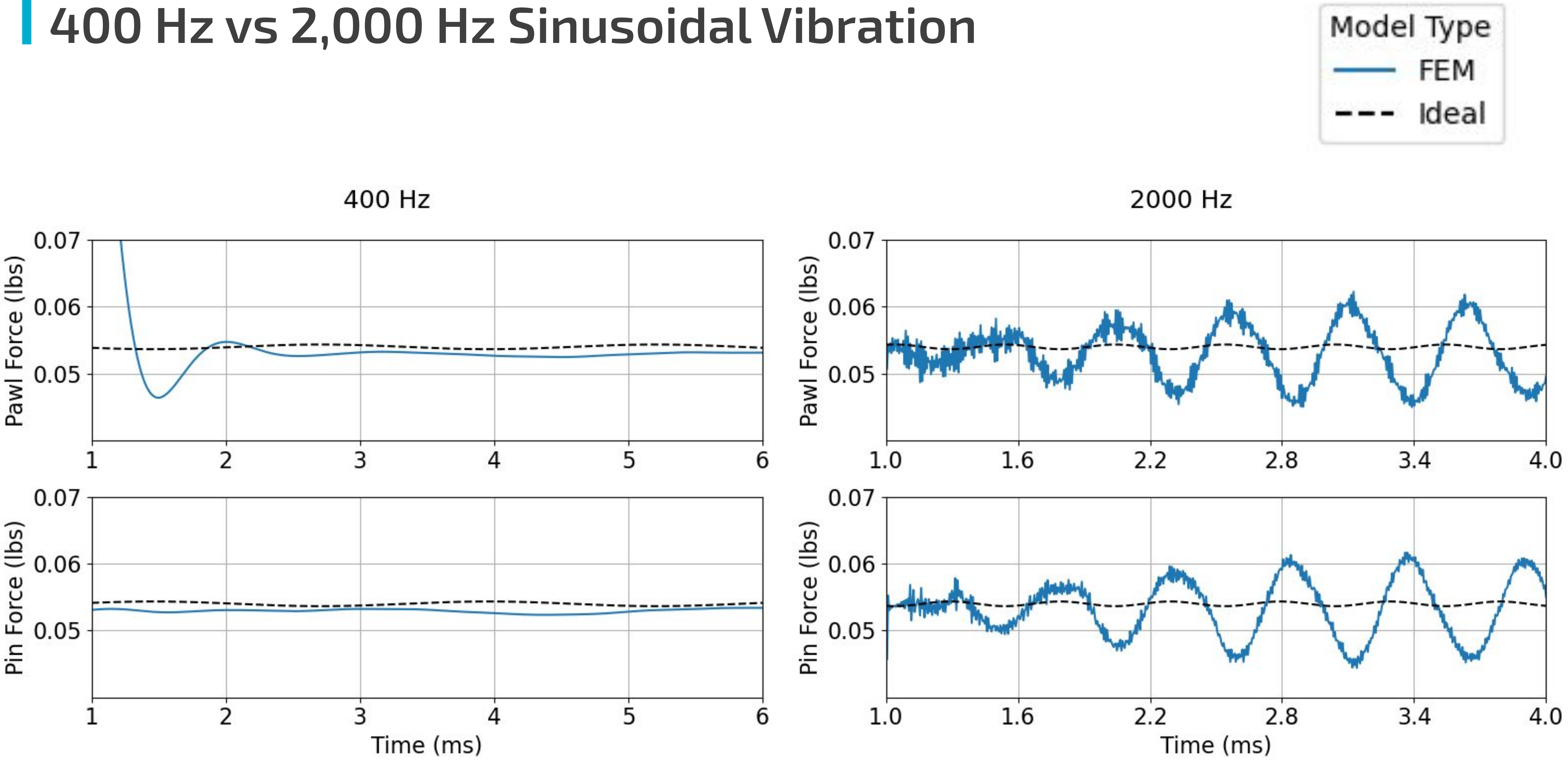
- Increasing or decreasing mesh density at the interface does not affect results
  - It could be possible to use larger elements to speed up simulation time

Number of Processors Used – Pin-Spring-Pawl

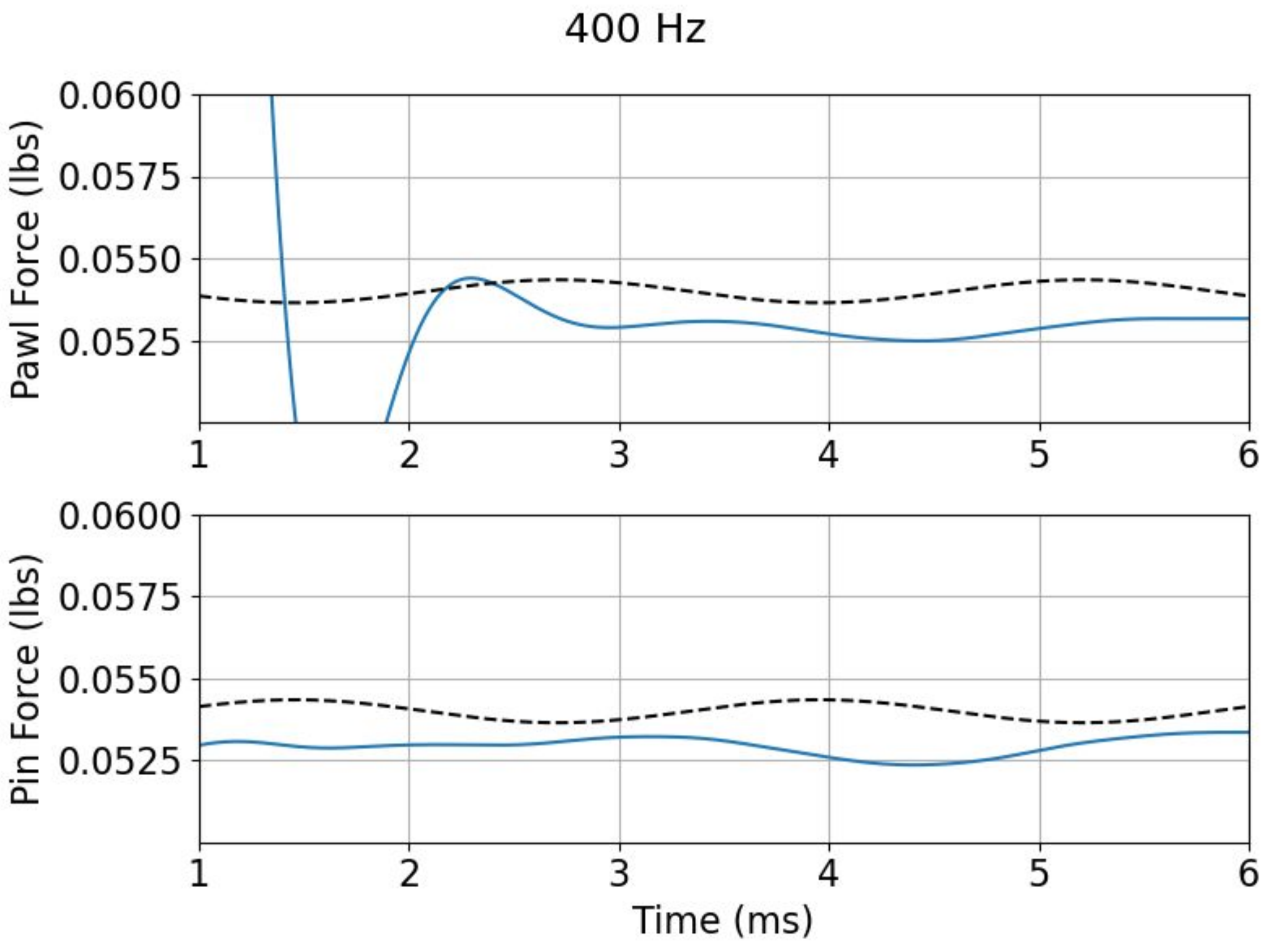


Submodel is insensitive to the number of cores used

400 Hz vs 2,000 Hz Sinusoidal Vibration



Zoomed 400 Hz



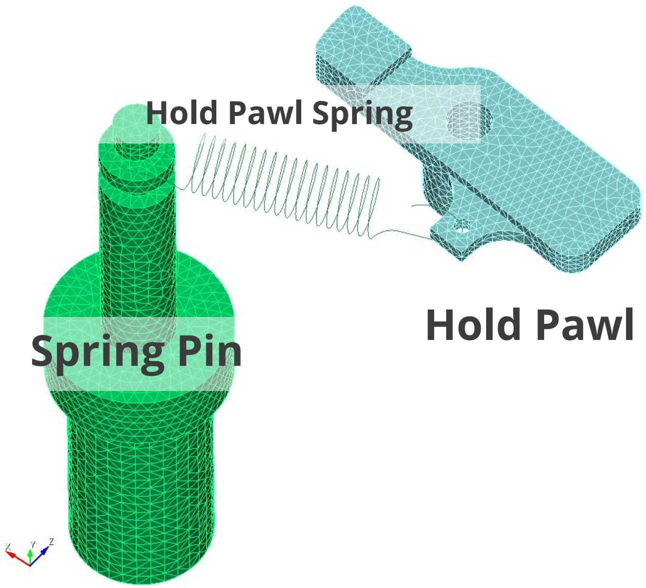
Pin-Spring-Pawl Submodel

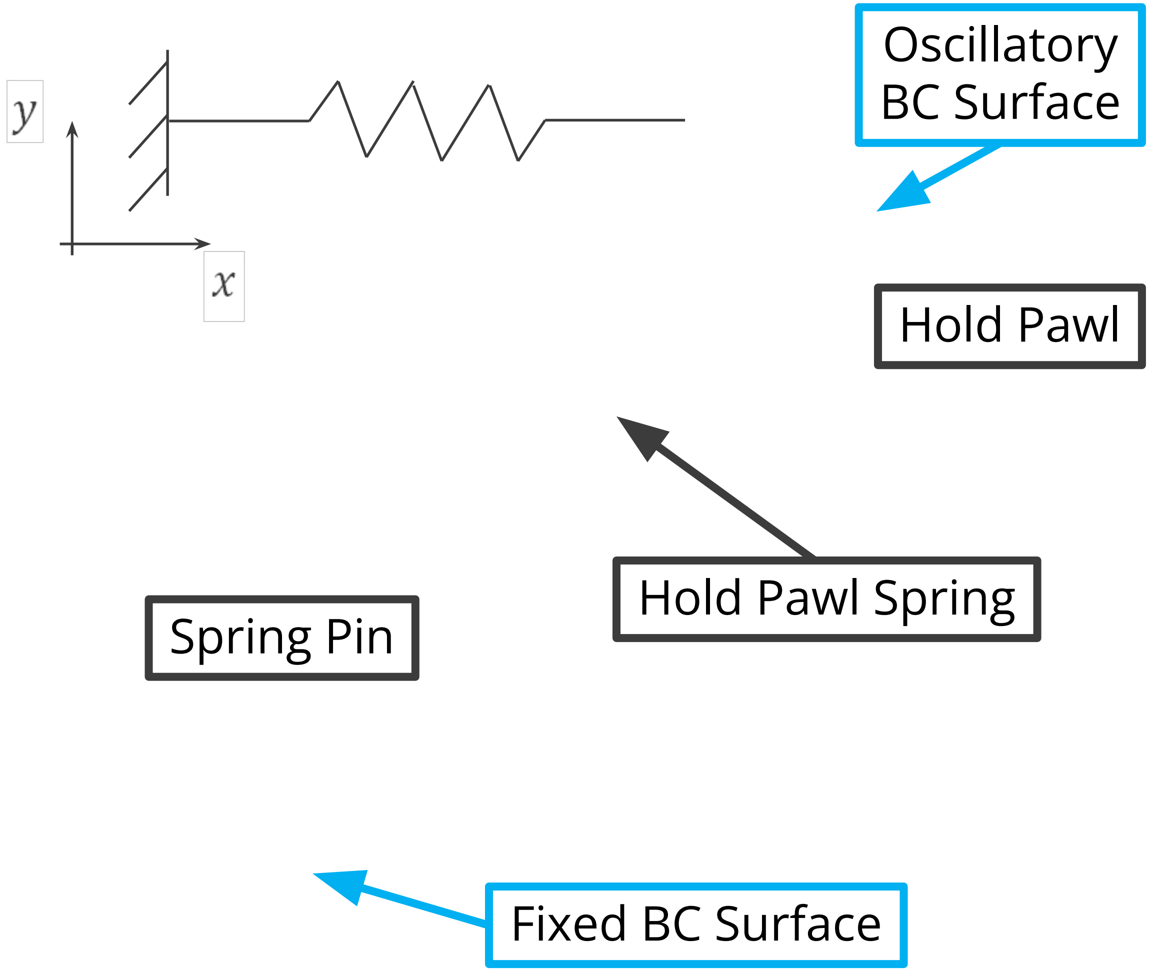
Parts:

- Hold Pawl
- Hold Pawl Spring
- Spring Pin

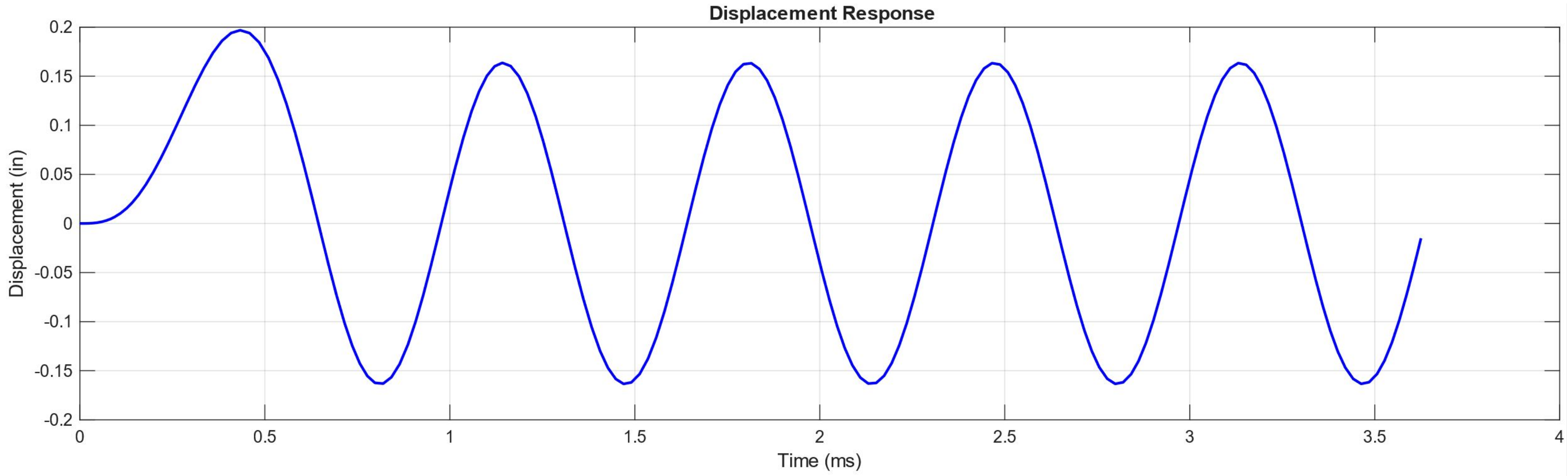
Quantities of interest:

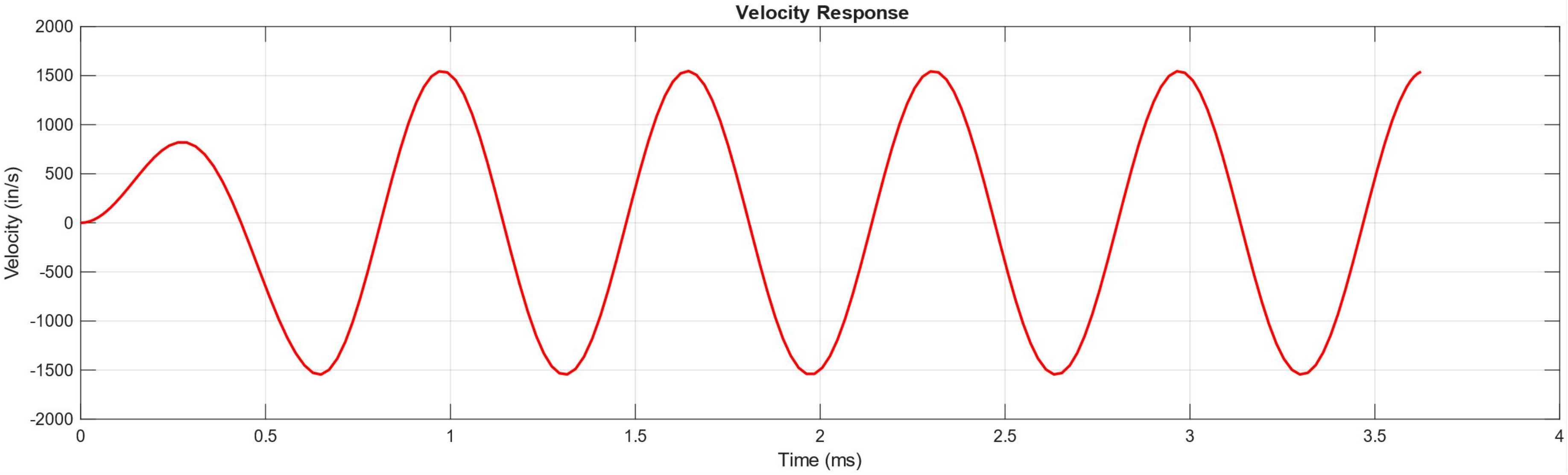
- Force from spring on pin and pawl



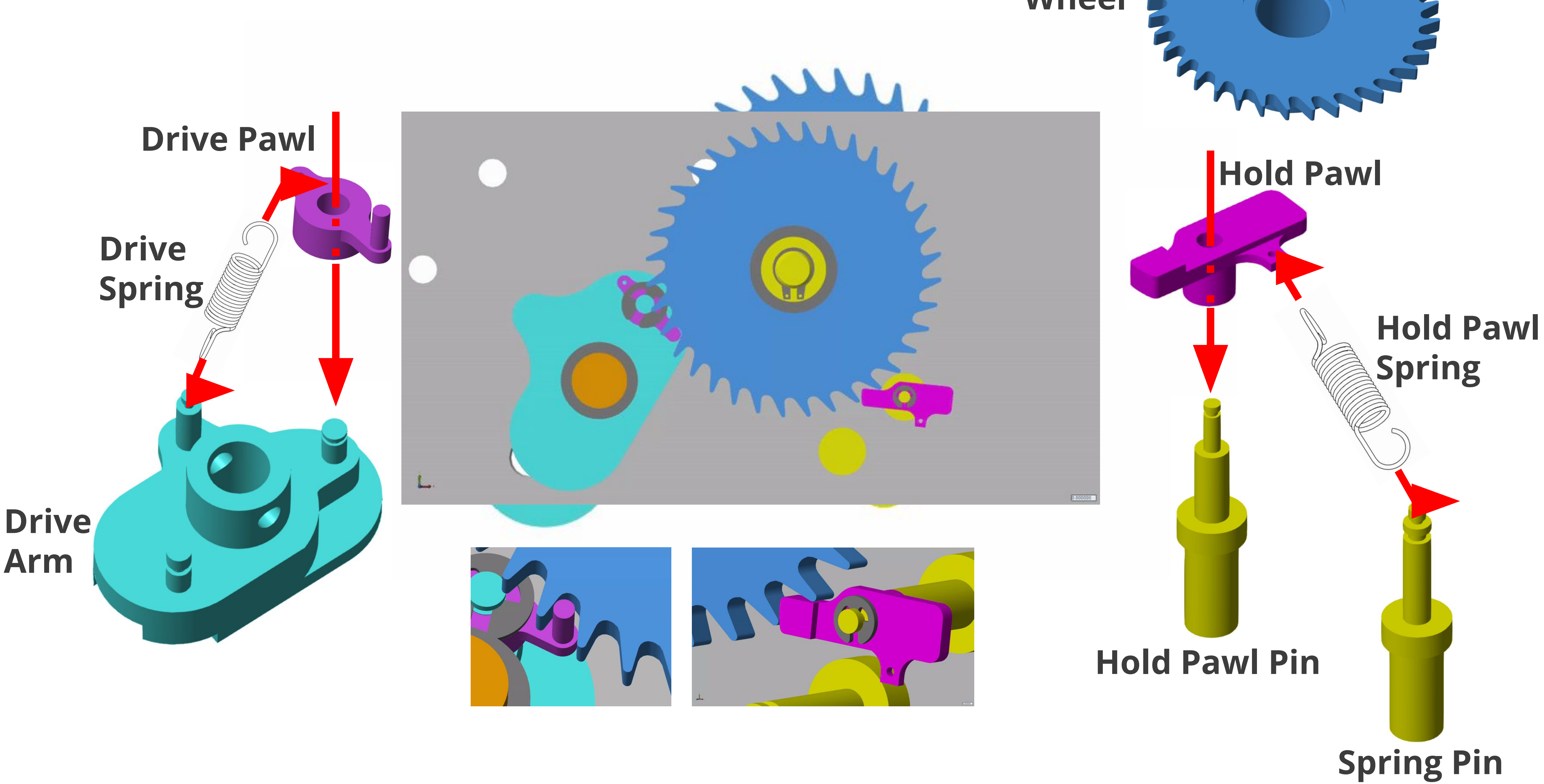


Preliminary ODE Ideal Results

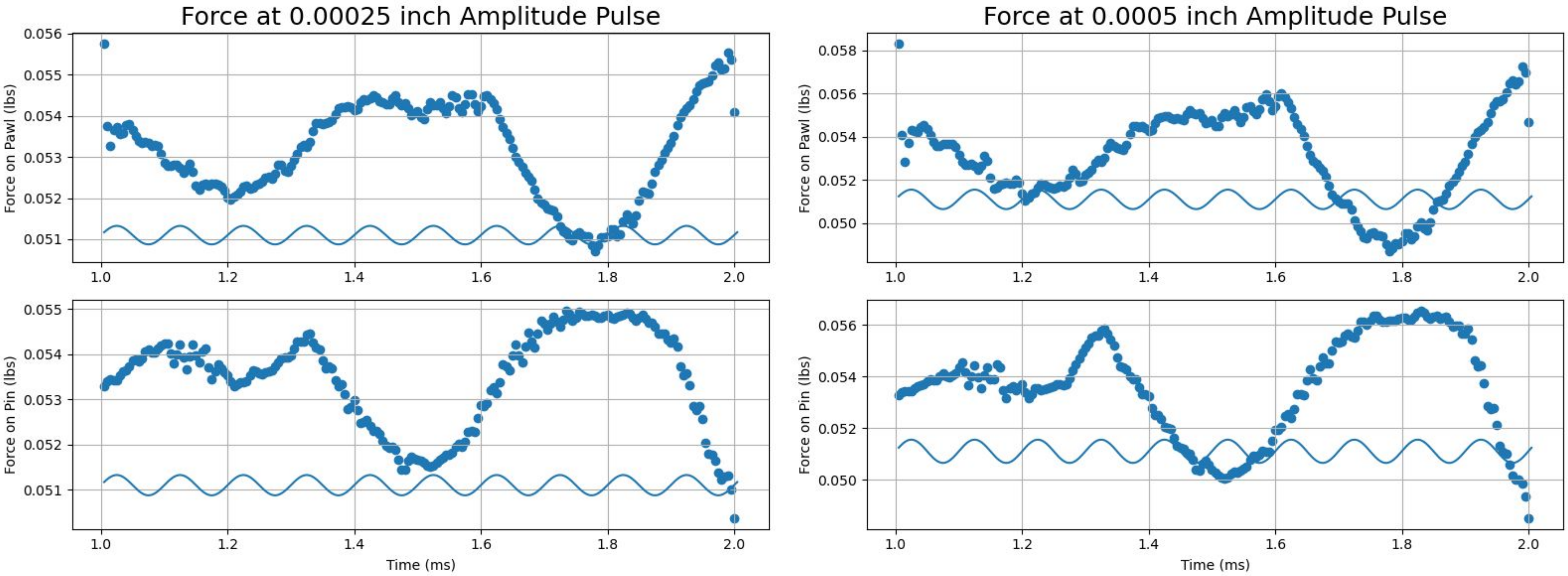




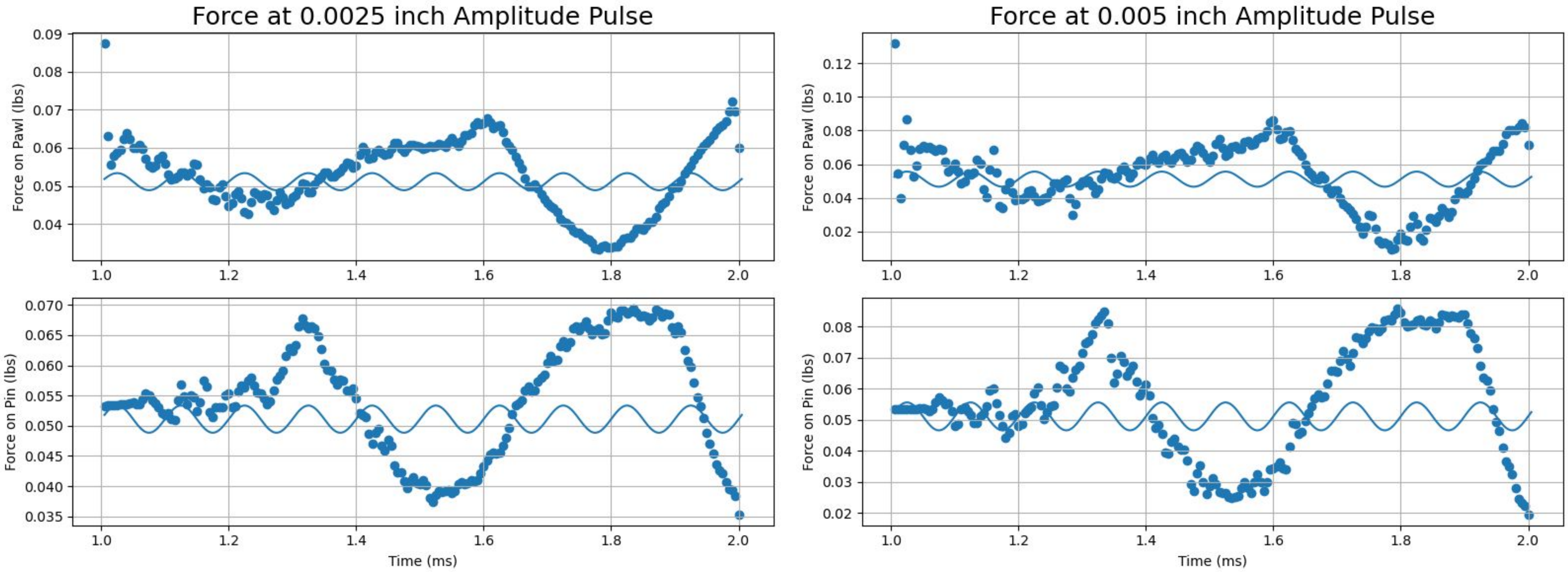
Ratcheting Mechanism Components



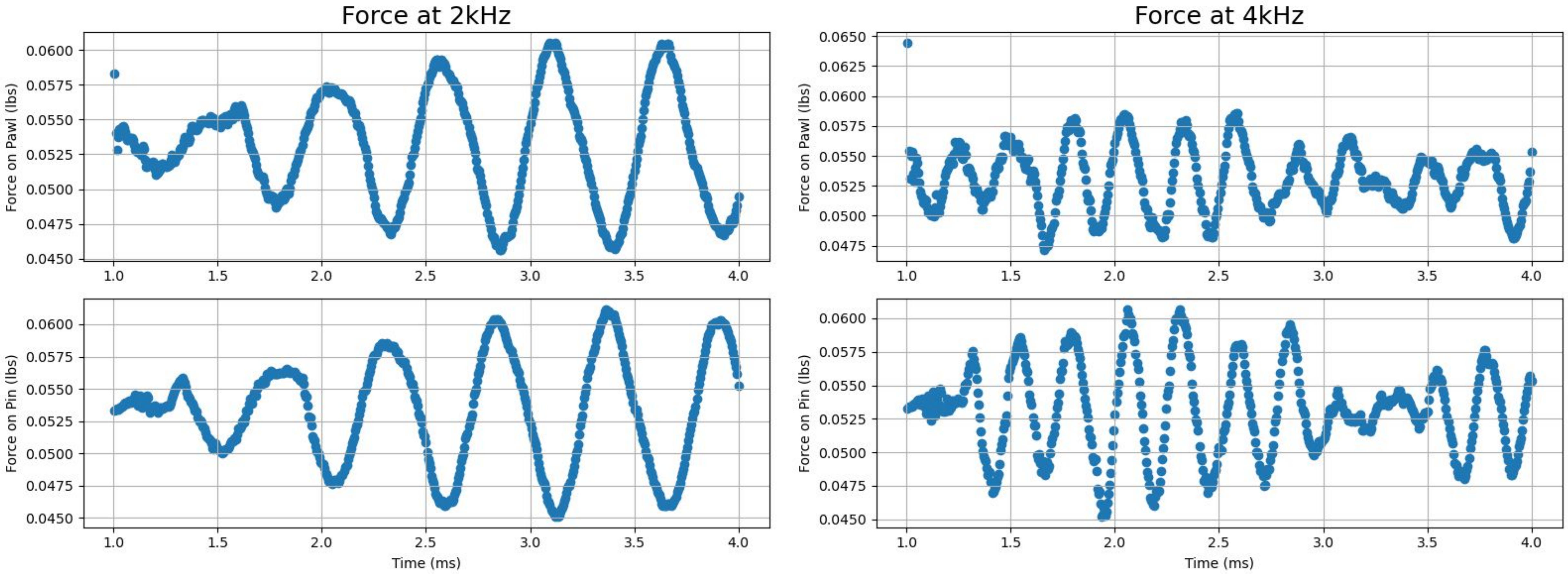
Amplitude Study (Pin-Spring-Pawl Sinusoidal)



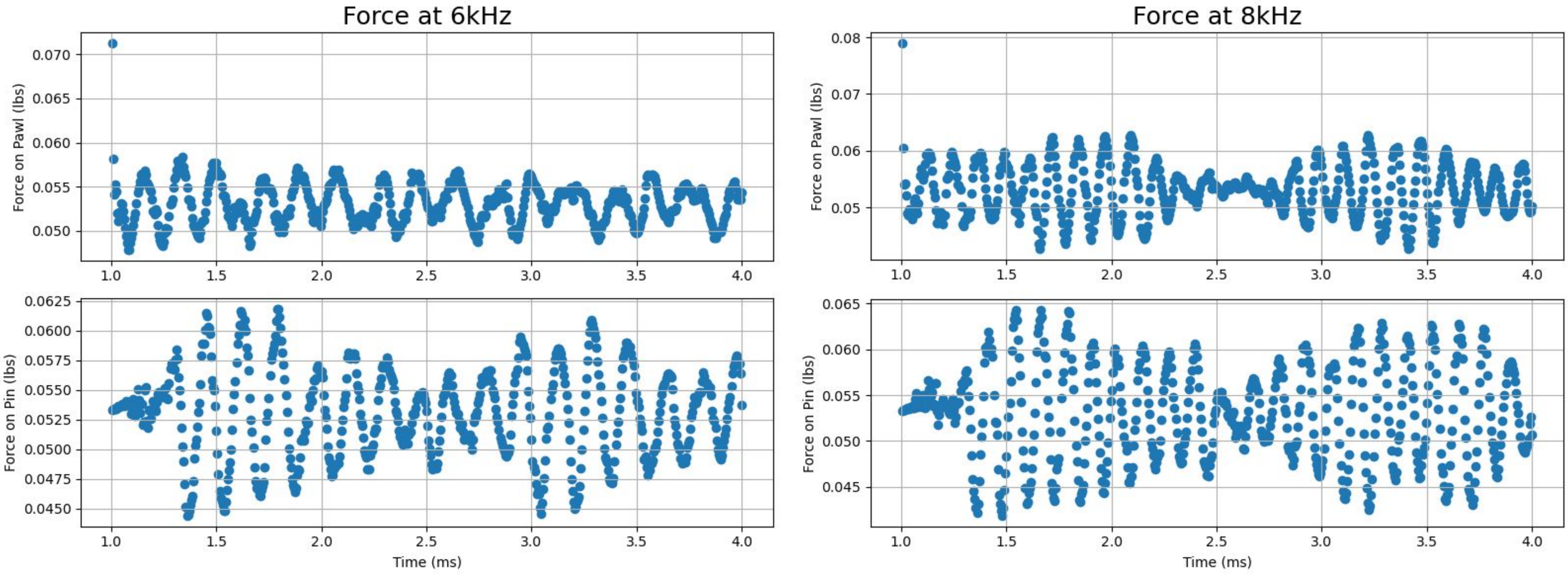
Amplitude Study (Pin-Spring-Pawl Sinusoidal) Cont.



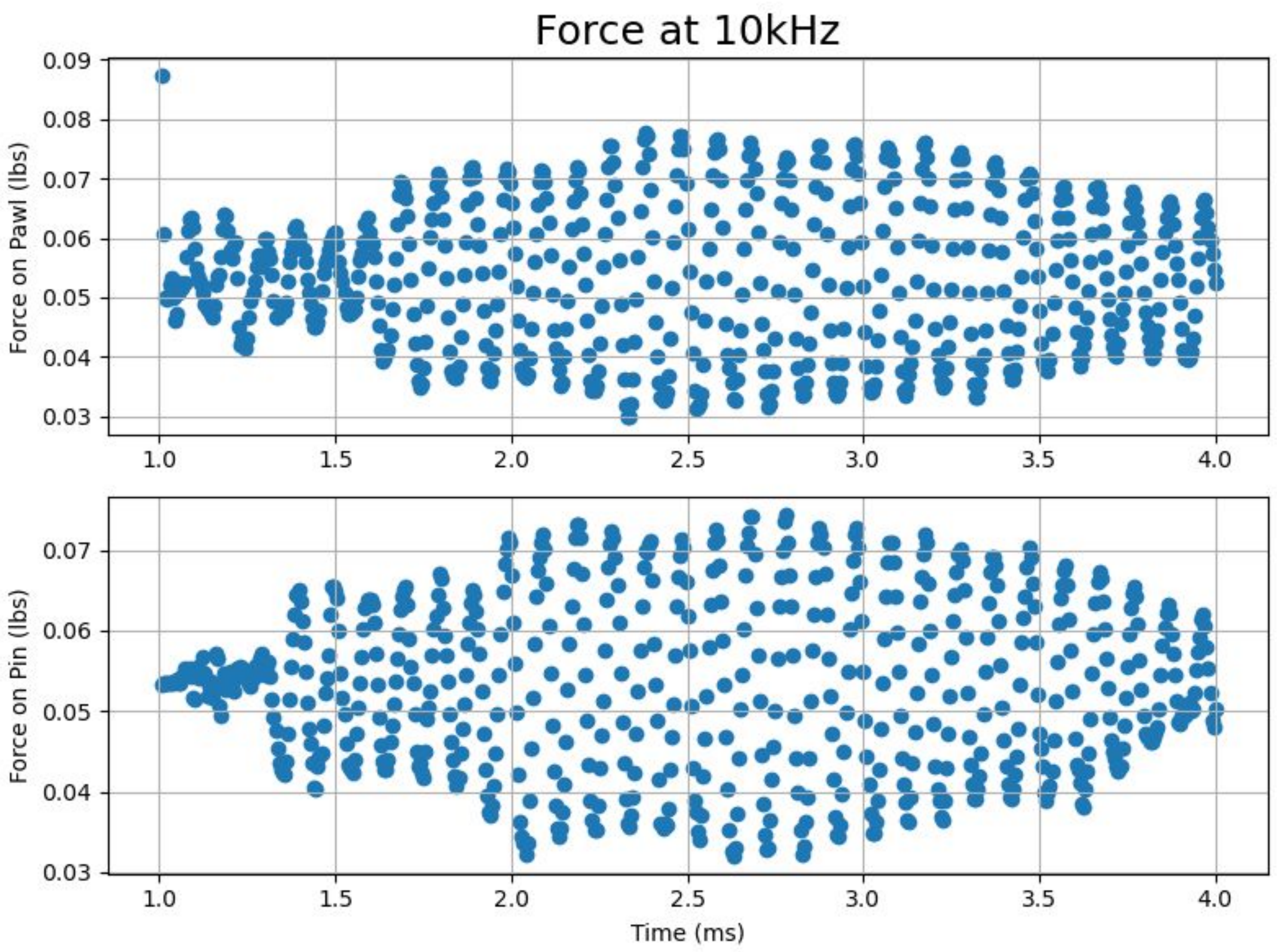
Frequency Study (Pin-Spring-Pawl Sinusoid)



Frequency Study (Pin-Spring-Pawl Sinusoid) Cont.

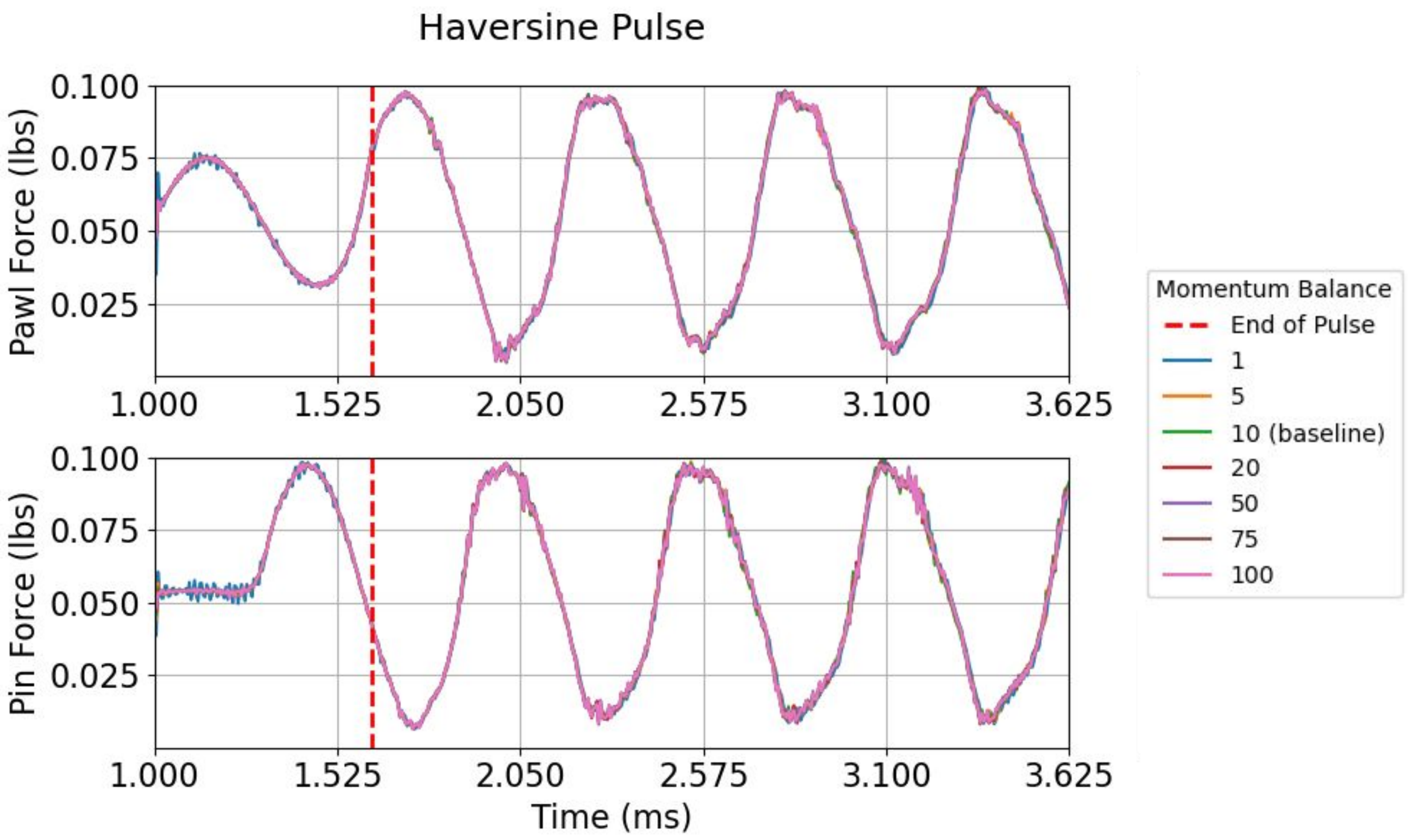


Frequency Study (Pin-Spring-Pawl Sinusoid) Cont.



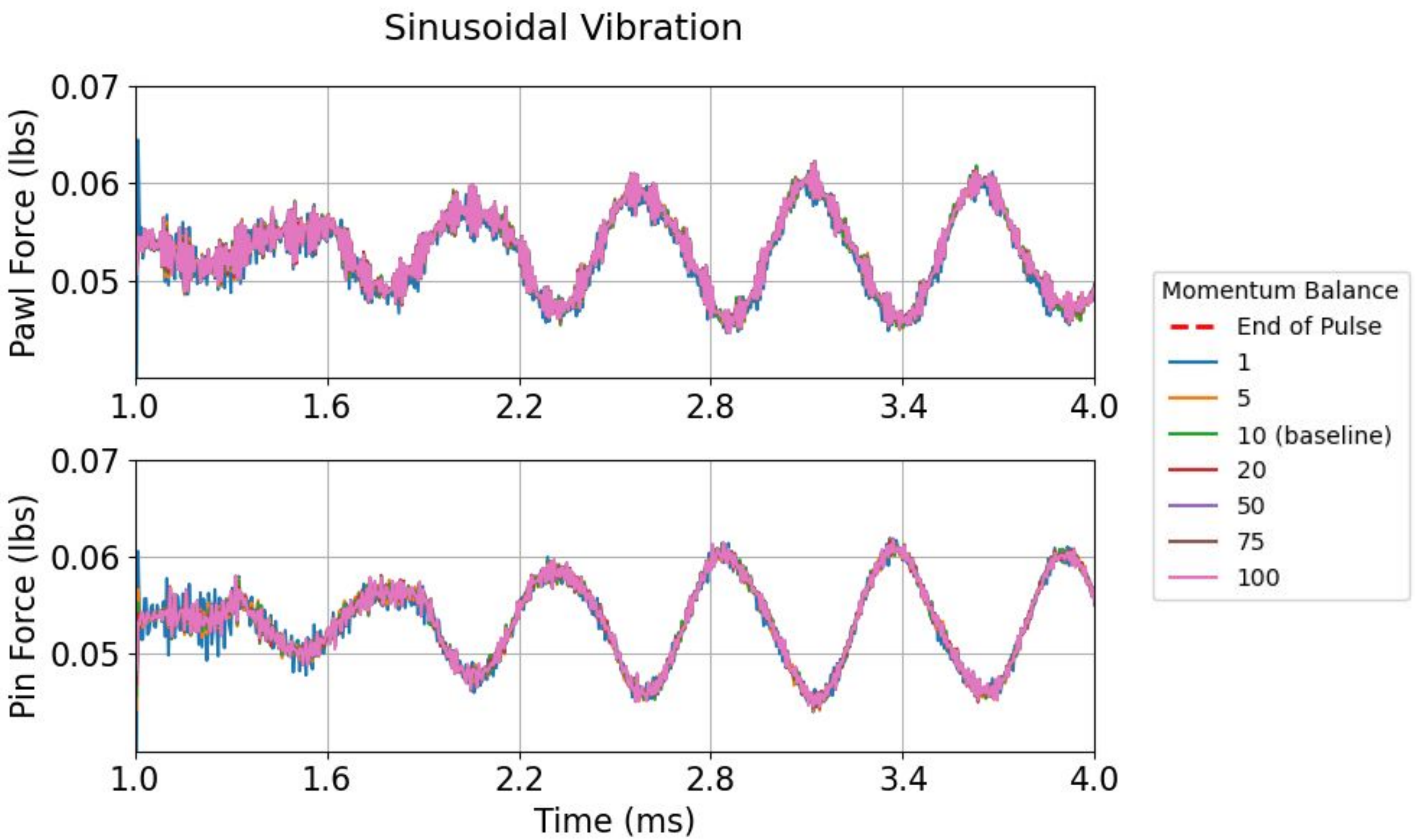
Momentum Balance Iteration – Pin-Spring-Pawl (Haversine Shock)

- Complete convergence between runs
- Using only one momentum balance iteration is noisier, but still tracks the general trend.
- Ideal model needs to be modified to account for inertial ringdown after environment has been applied.



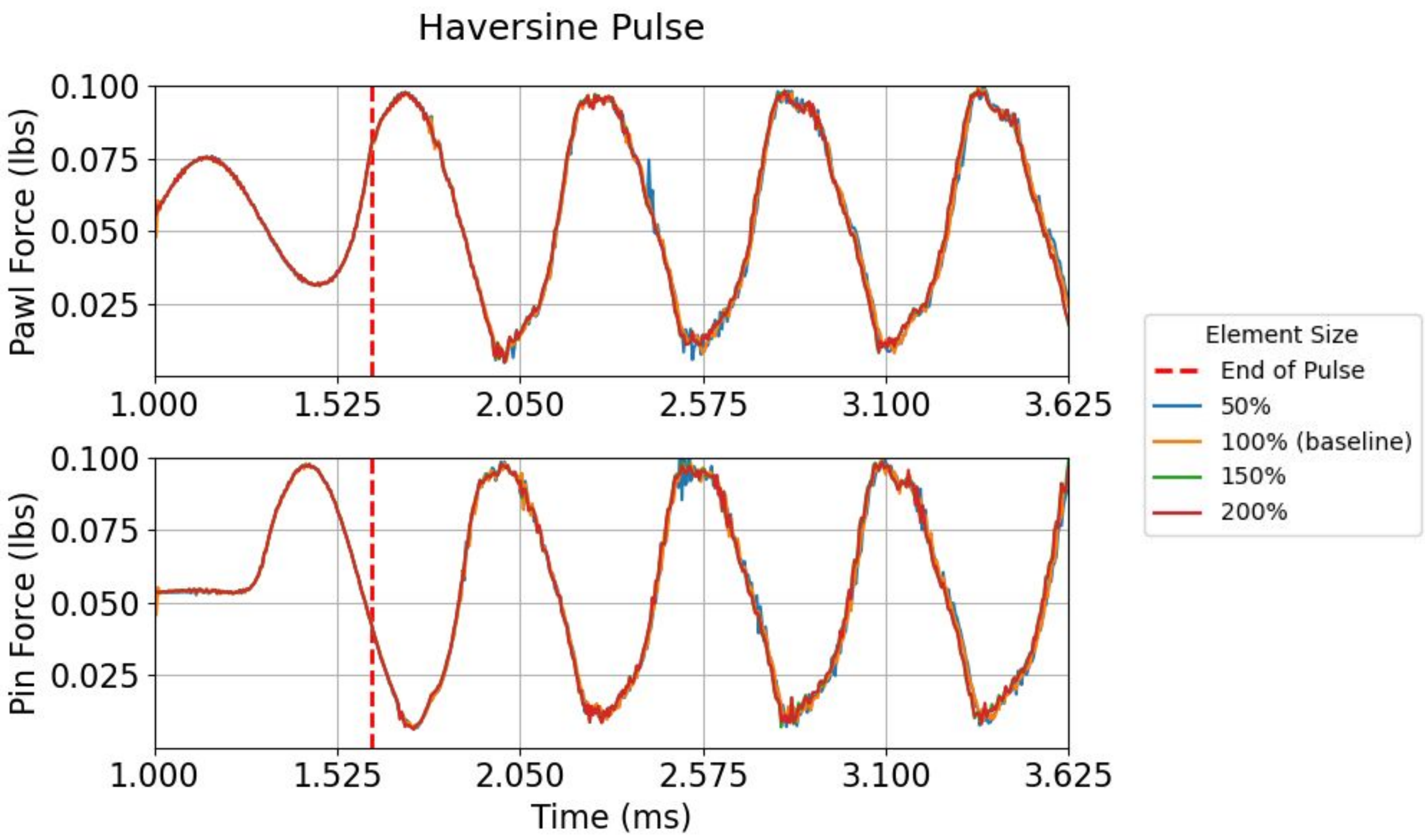
Momentum Balance Iteration – Pin-Spring-Pawl (Sinusoidal Vibration)

- Complete convergence between runs
- Ideal model underpredicts the force due to the environment



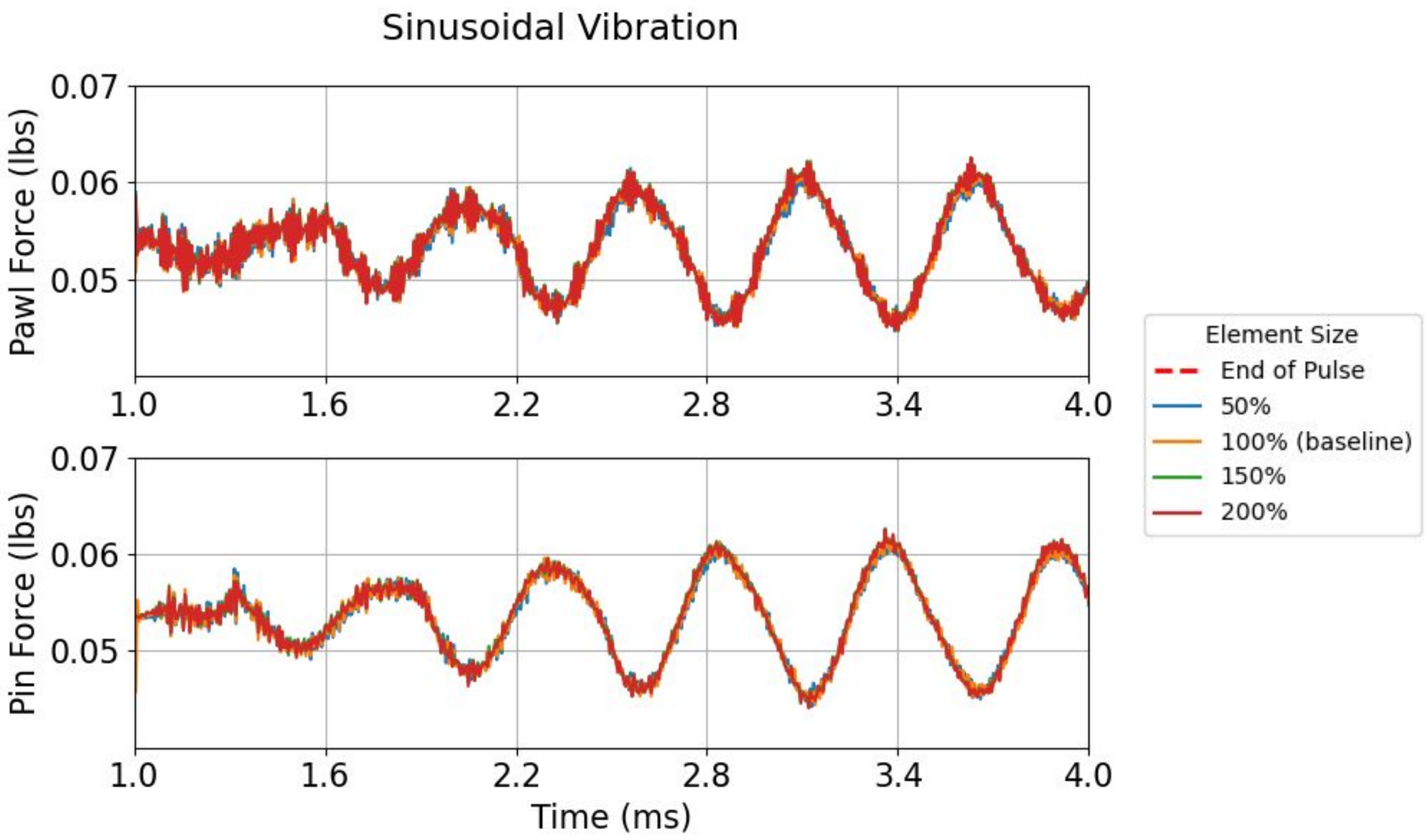
Mesh Density – Pin-Spring-Pawl (Haversine Shock)

- Complete convergence between runs
- Ideal model needs to be modified to account for inertial ringdown after environment has been applied.



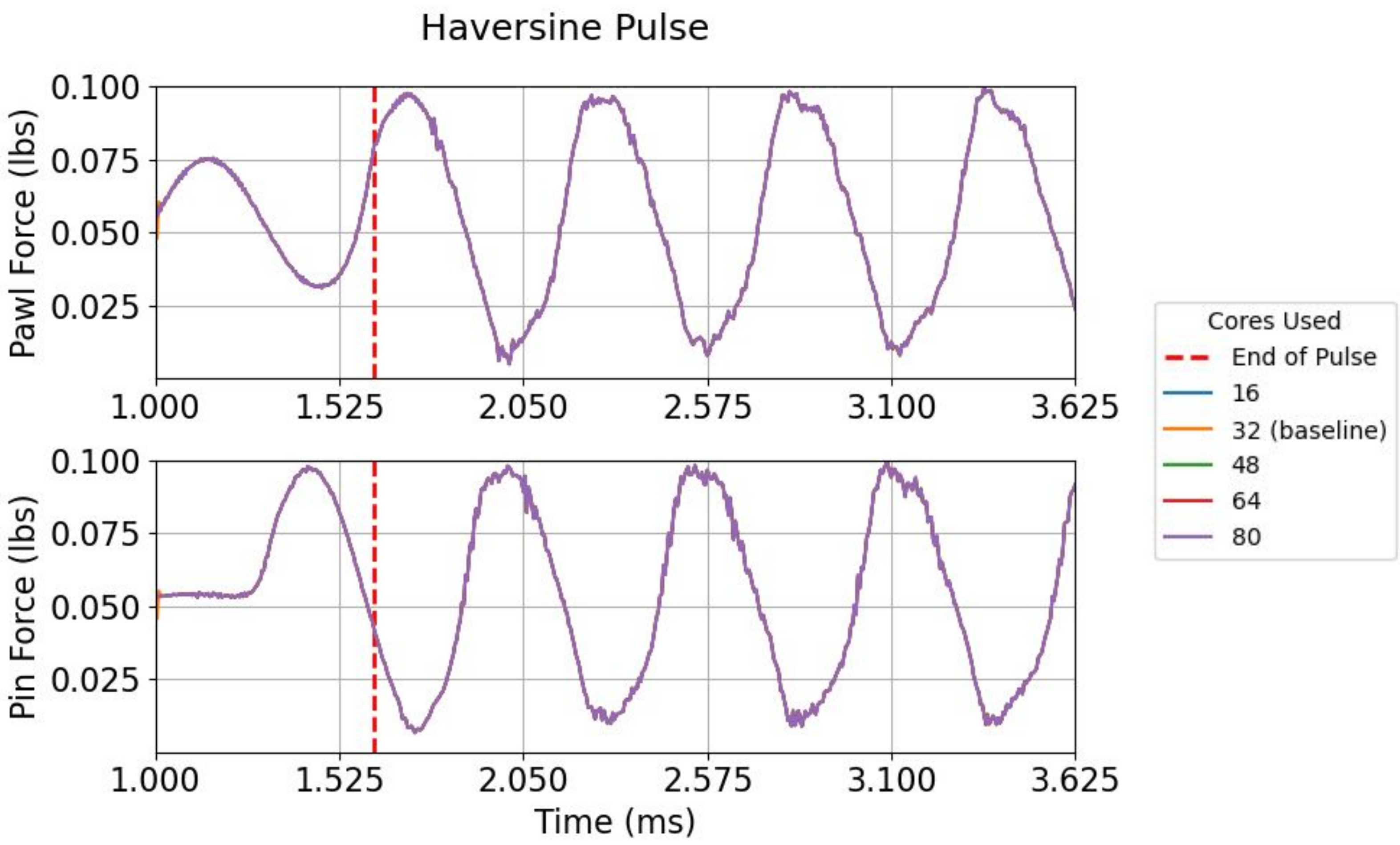
Mesh Density – Pin-Spring-Pawl (Sinusoidal Vibration)

- Complete convergence between runs



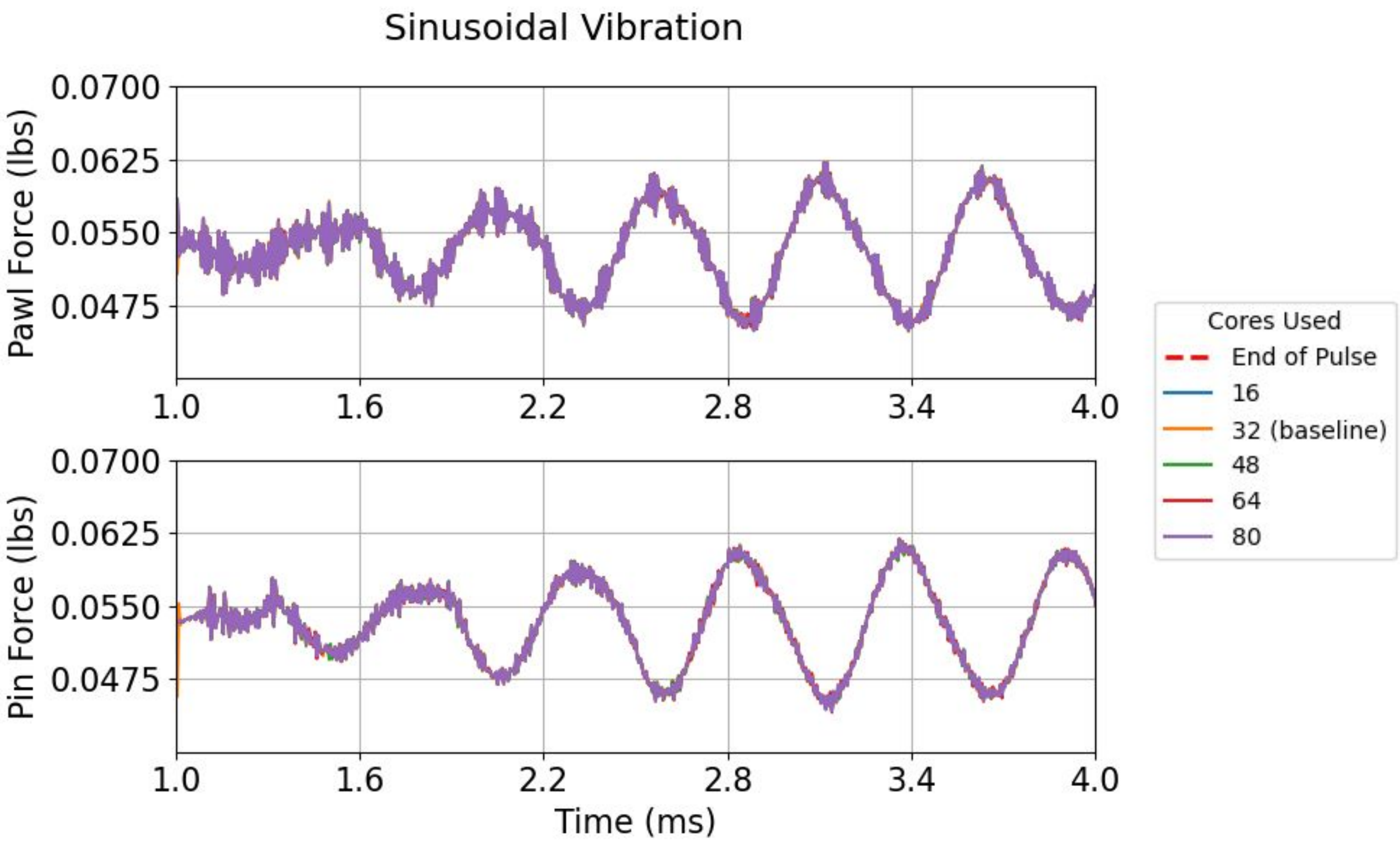
Number of Processors Used – Pin-Spring-Pawl (Haversine Shock)

- Complete convergence between runs



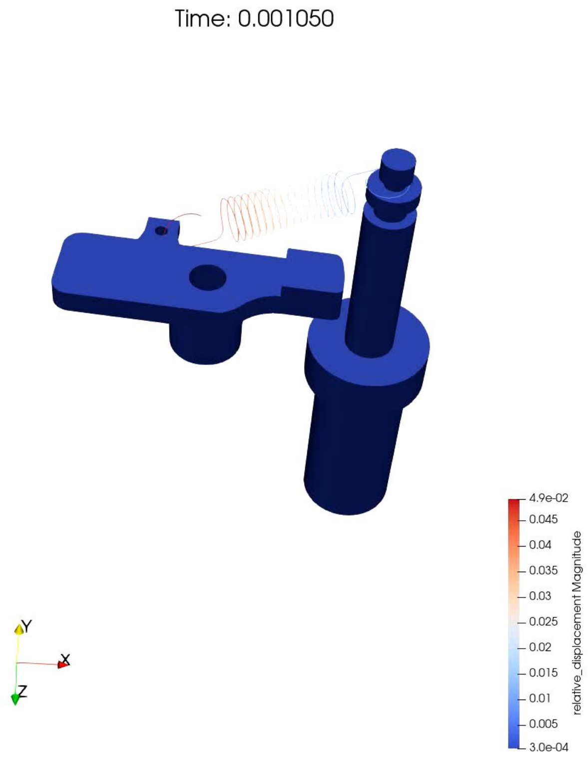
Number of Processors Used – Pin-Spring-Pawl (Sinusoidal Vibration)

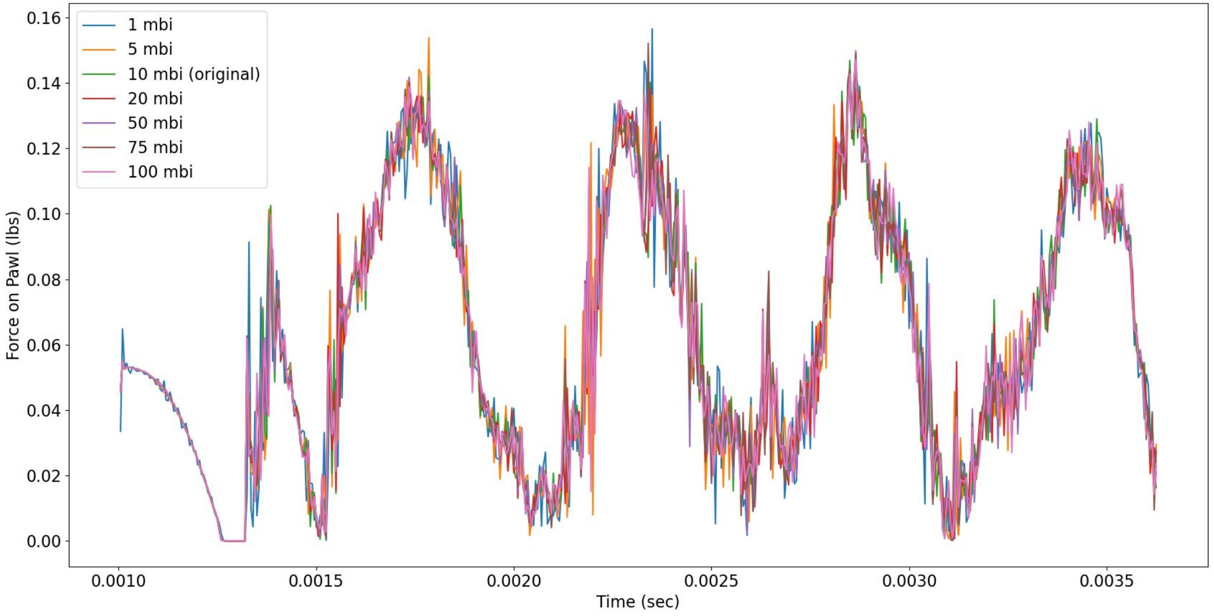
- Complete convergence between runs

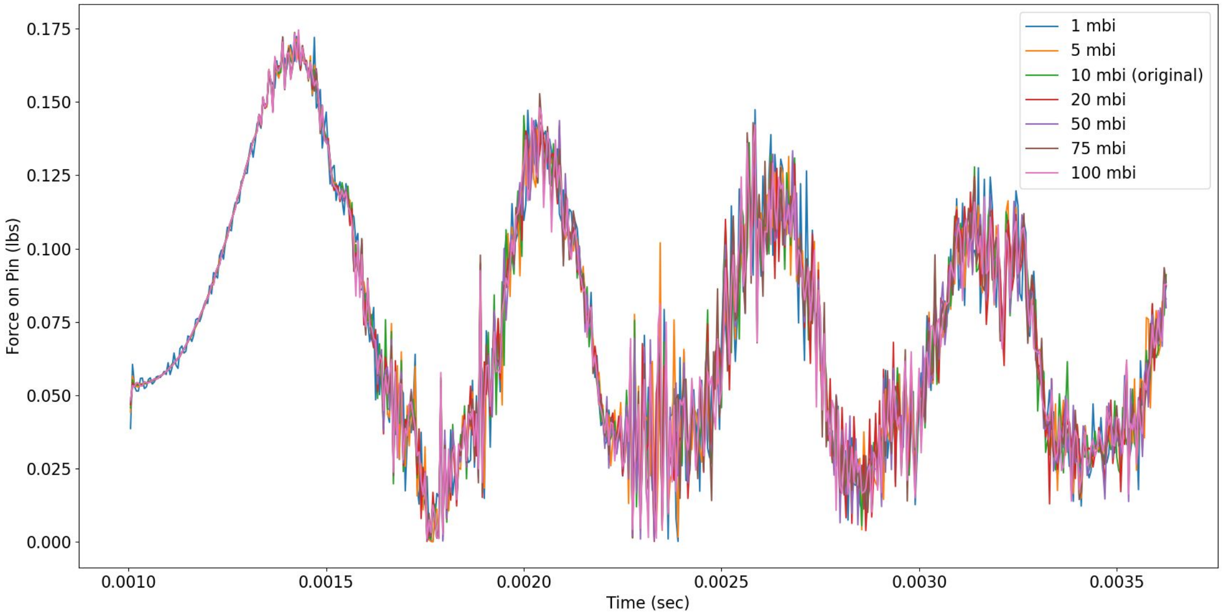


Haversine Pulse (6000 G's, 0.5 ms, +x)

- Little to no variation when varying the number of momentum balance iterations used by Sierra.
- Slightly more noise in the 1 mbi response, but the general trend matches.

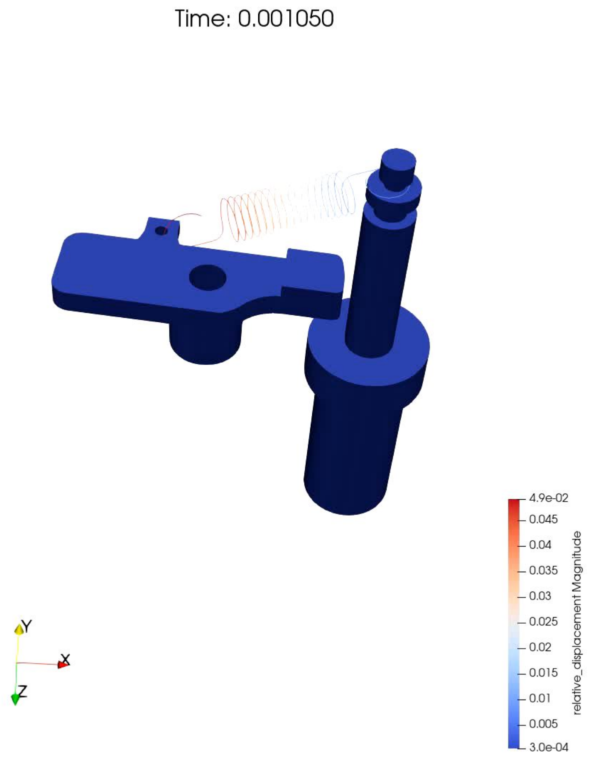


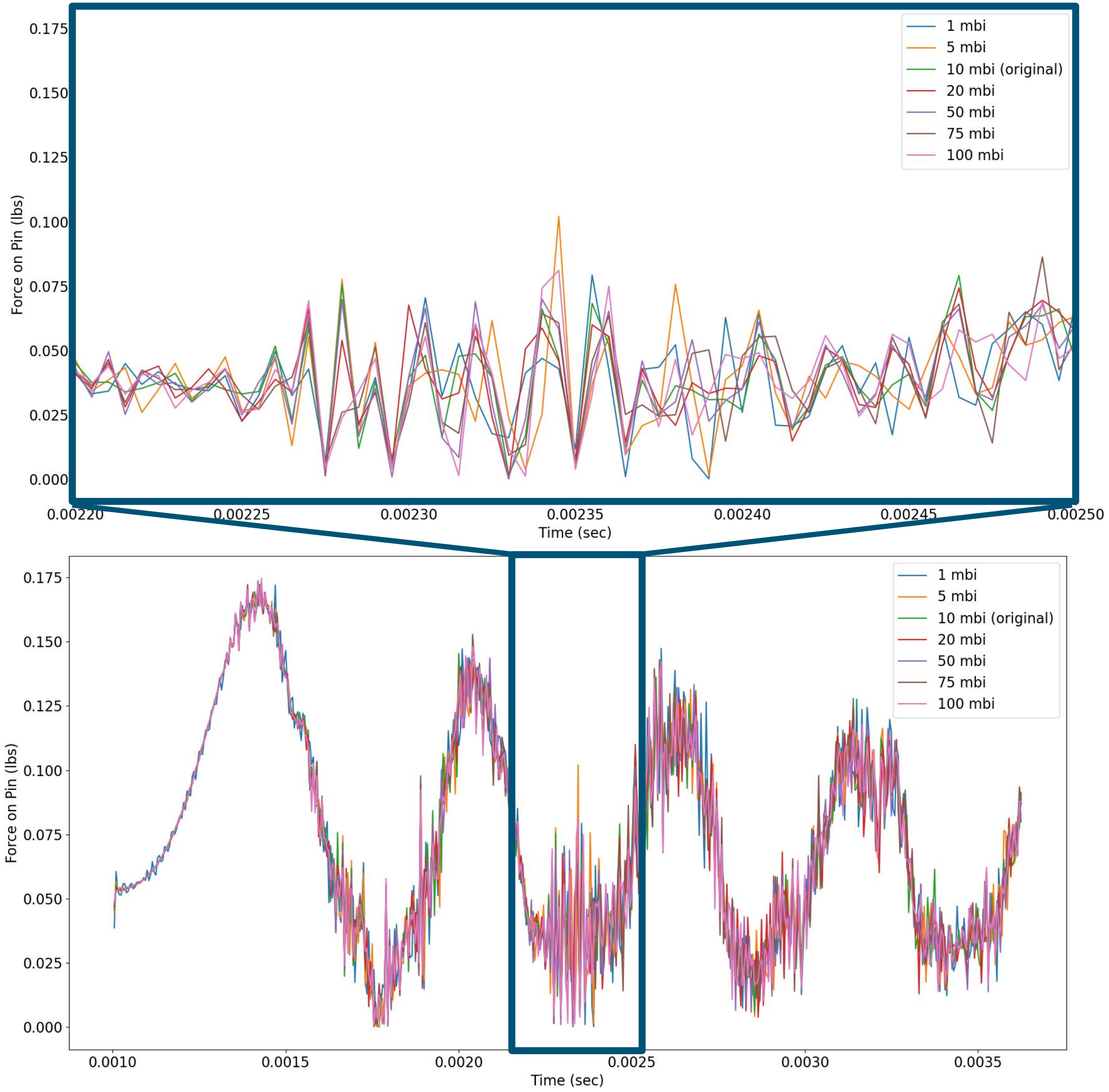




Haversine Pulse (6000 G's, 0.5 ms, +x)

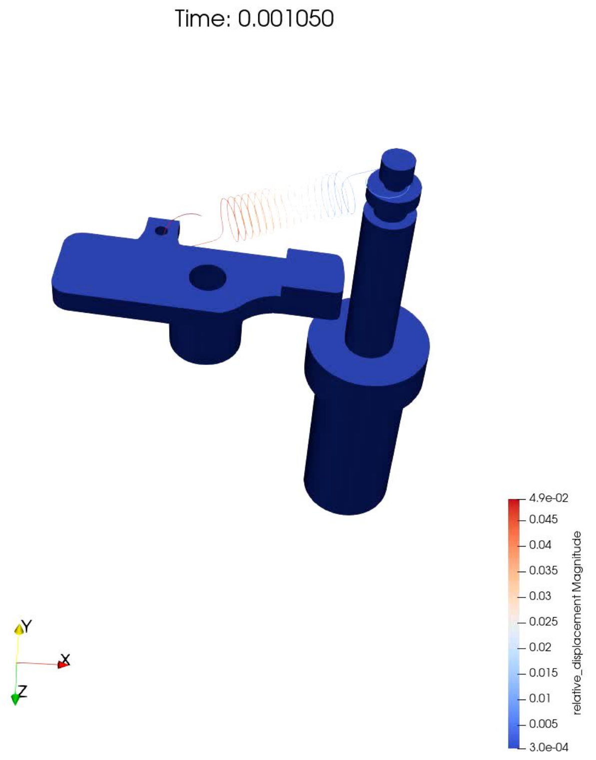
- Little to no variation when varying the number of momentum balance iterations used by Sierra.
- Slightly more noise in the 1 mbi response, but the trend holds.

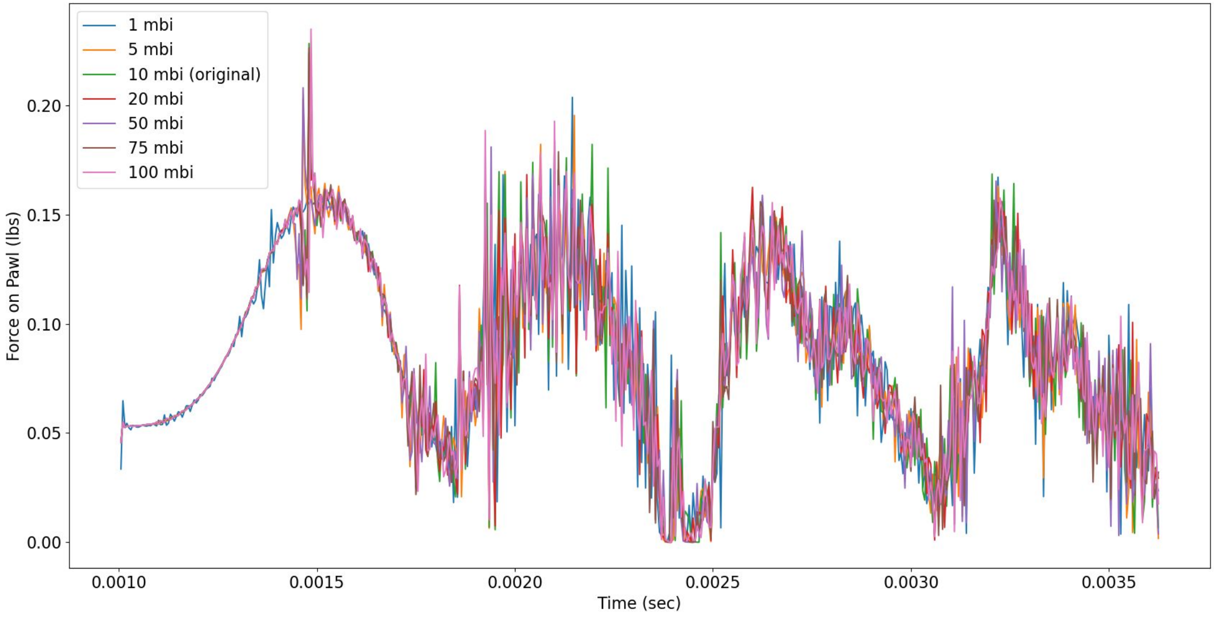


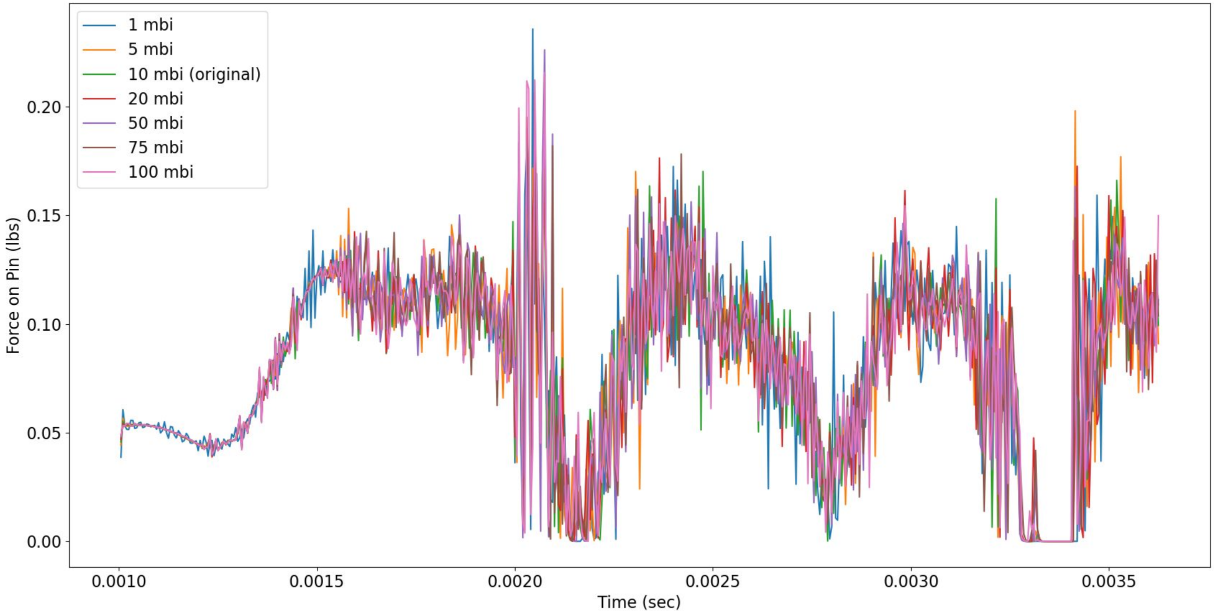


Haversine Pulse (6000 G's 0.5 ms, +z)

- Same story as the x-direction
- Significant disconnect on the Pin at around 3.4 ms







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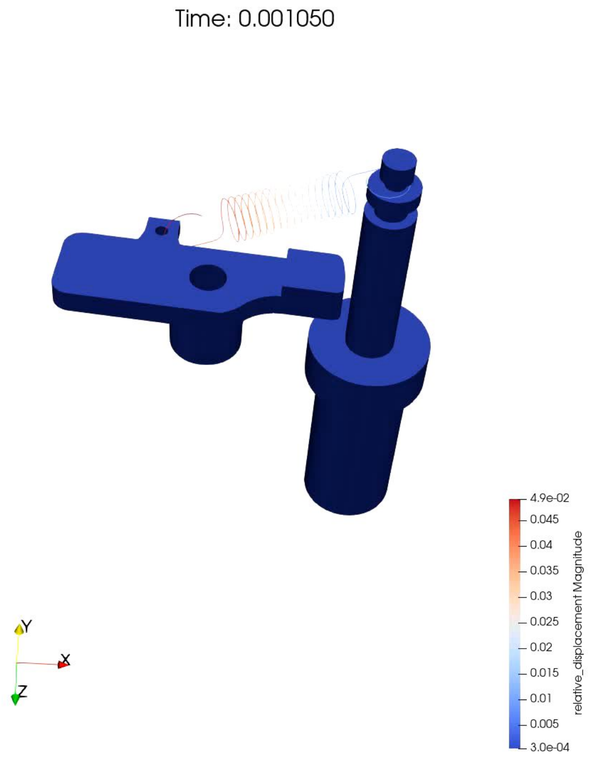
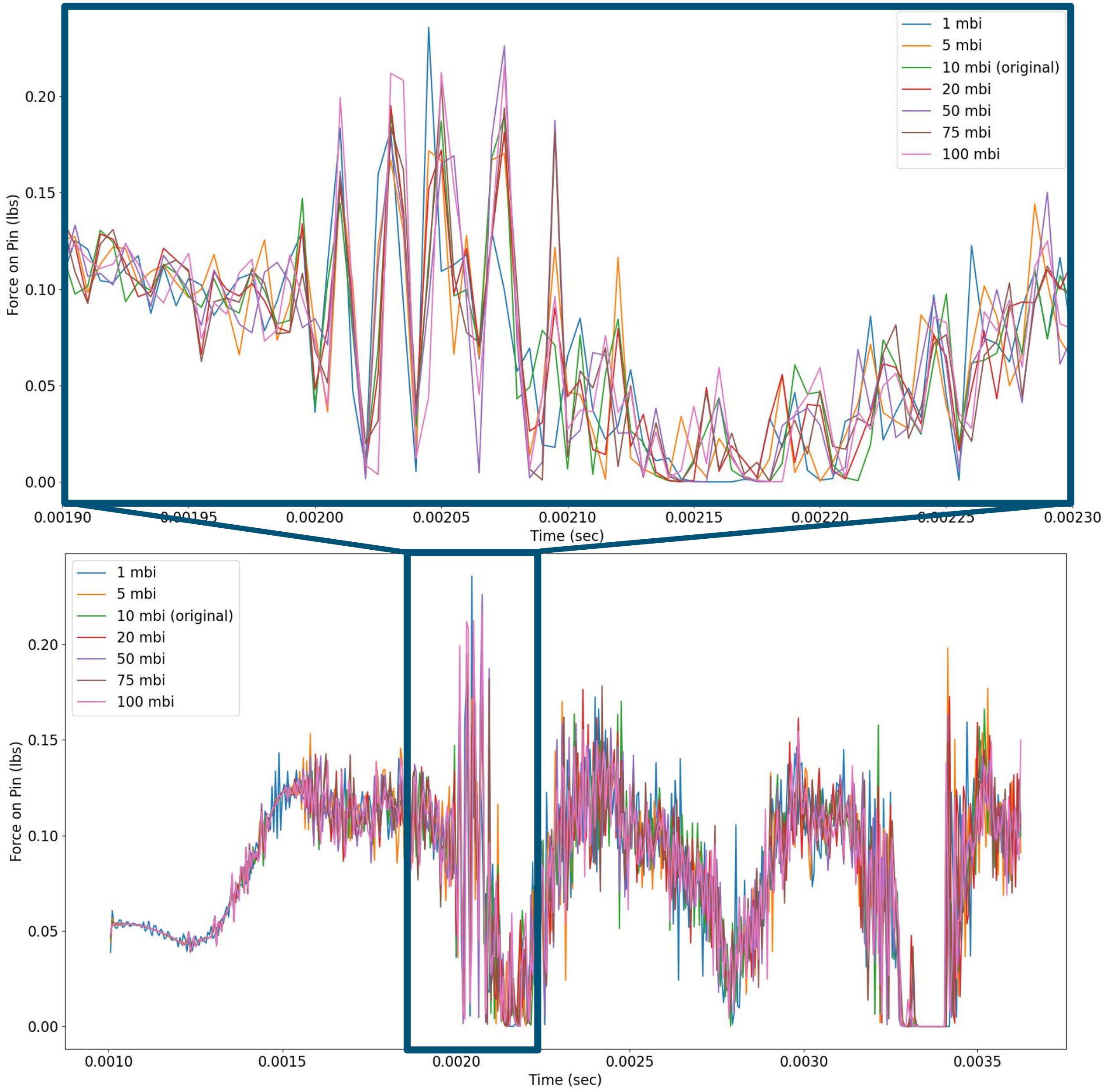
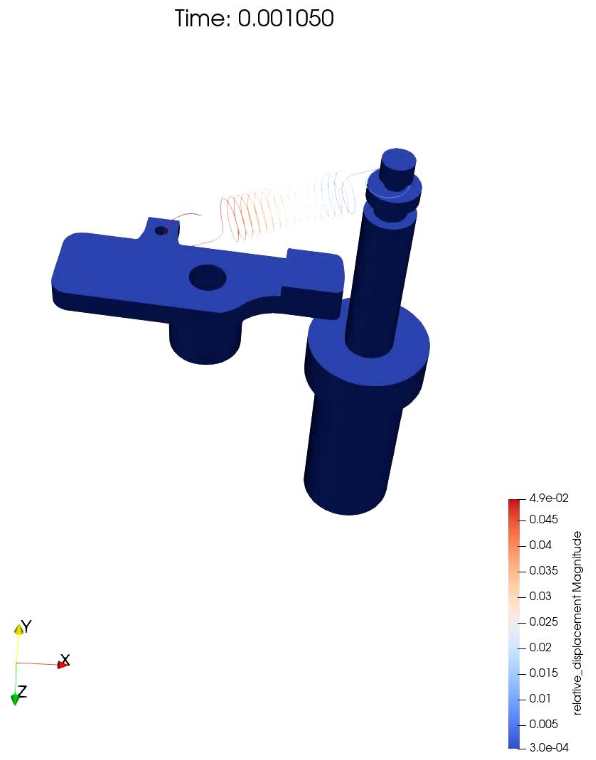
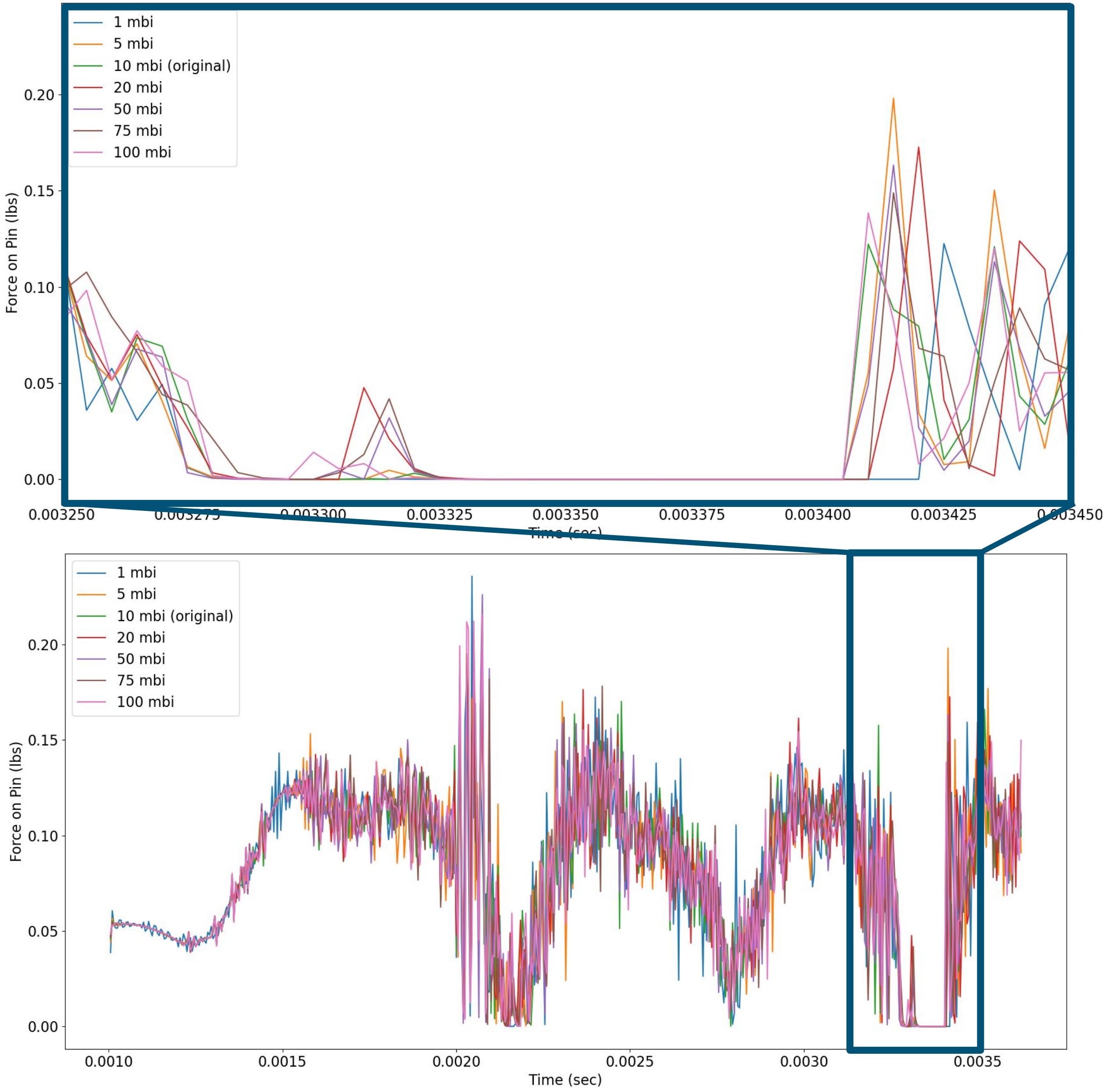




Haversine Pulse (6000 G's, 0.5 ms, +z)

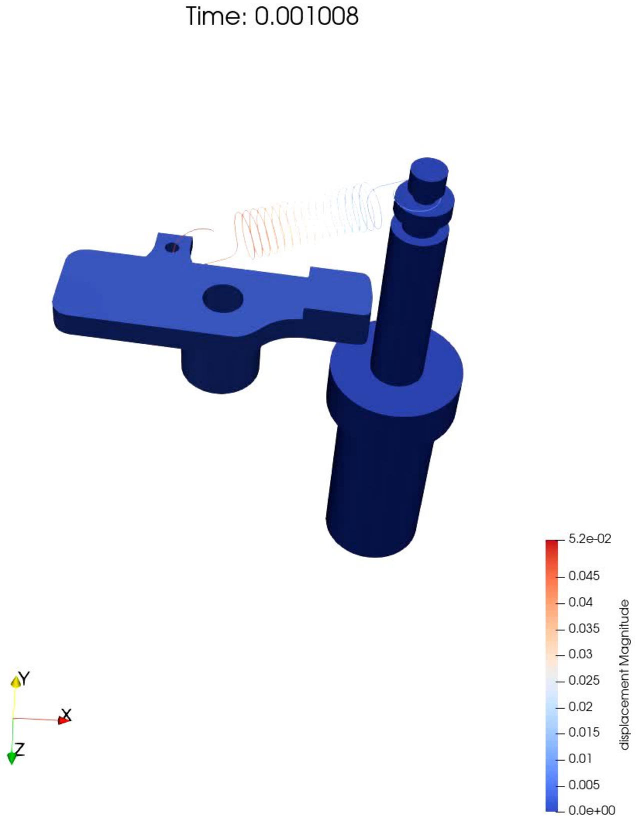
- Same story as the x-direction
- Significant disconnect on the Pin at around 3.4 ms

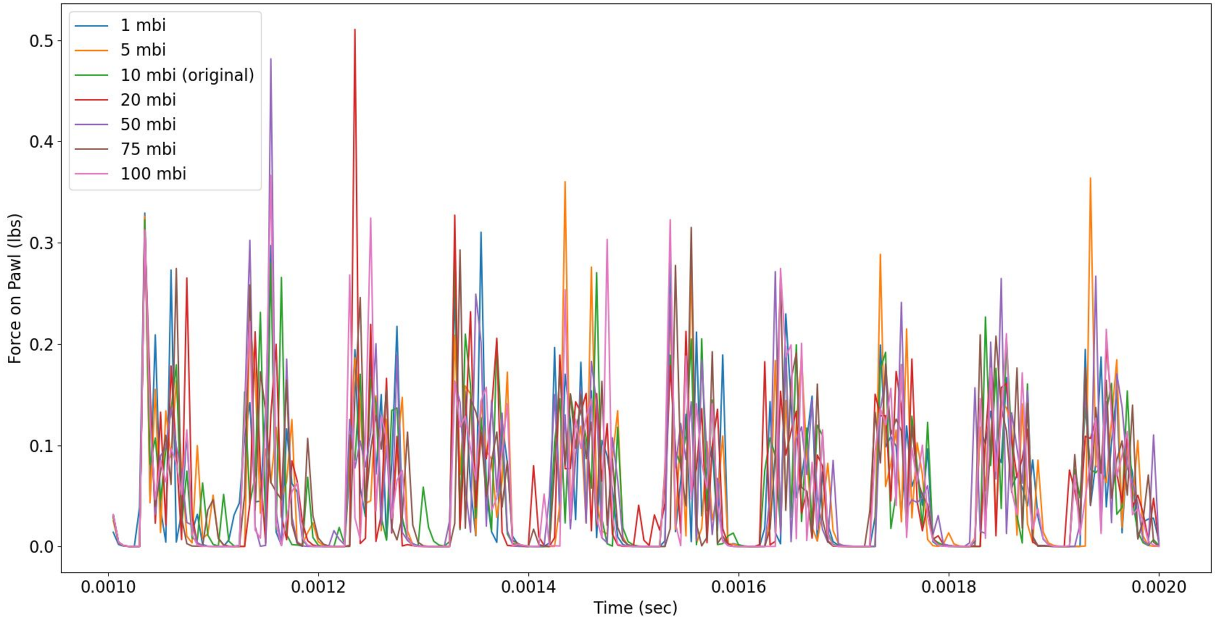


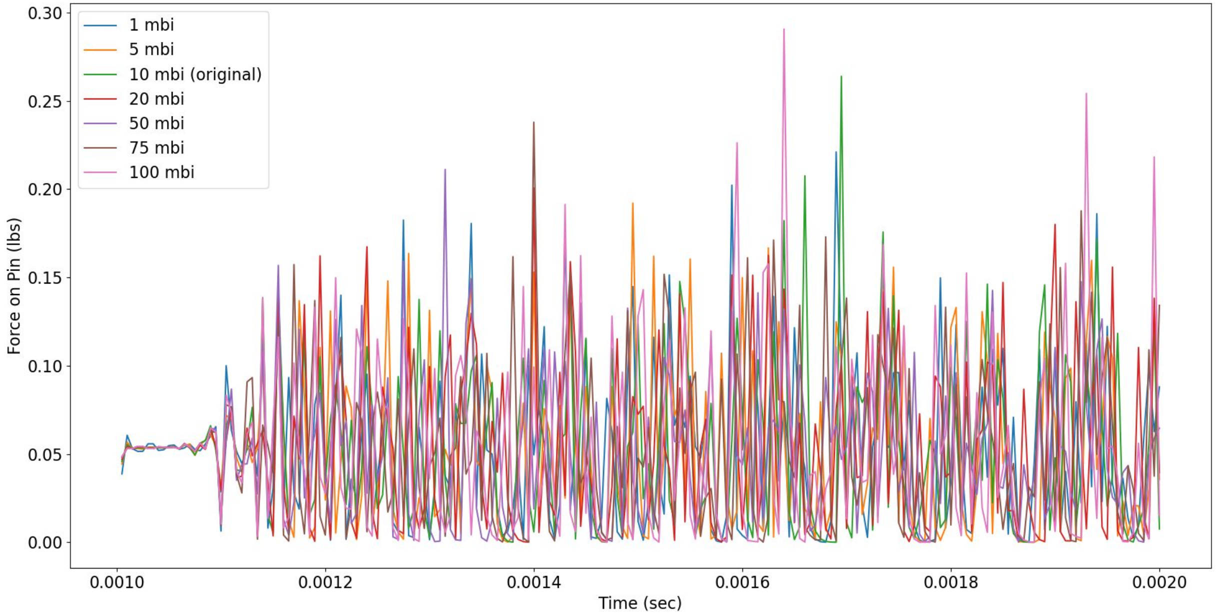


Sinusoid Displacement of Pawl (0.005 inches, +x)

- Not sure what to make of these results
- Significant differences in amplitudes of peaks
- Convergence during loss of contact

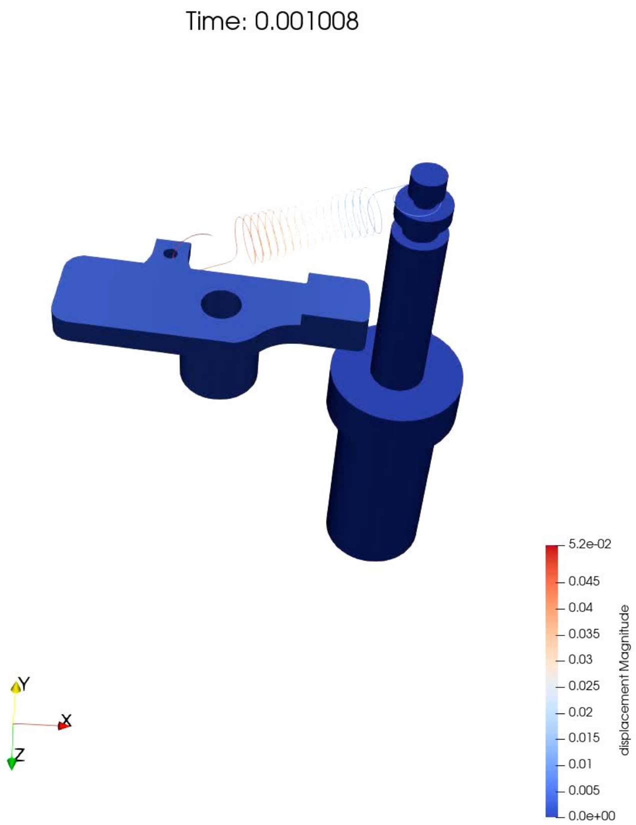


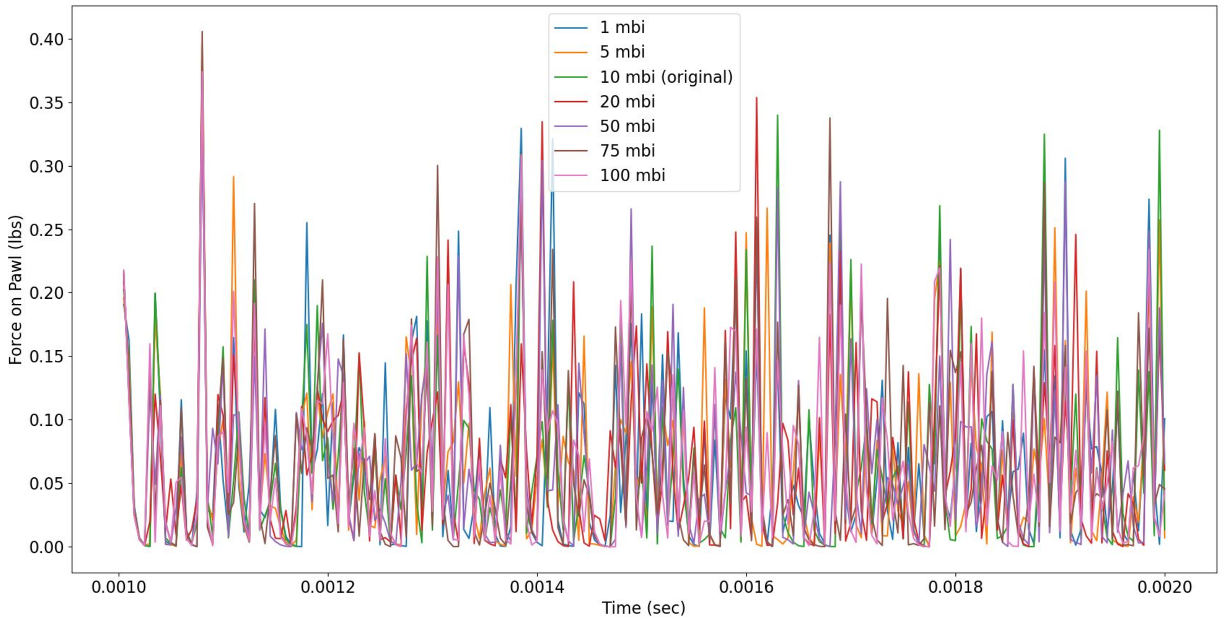


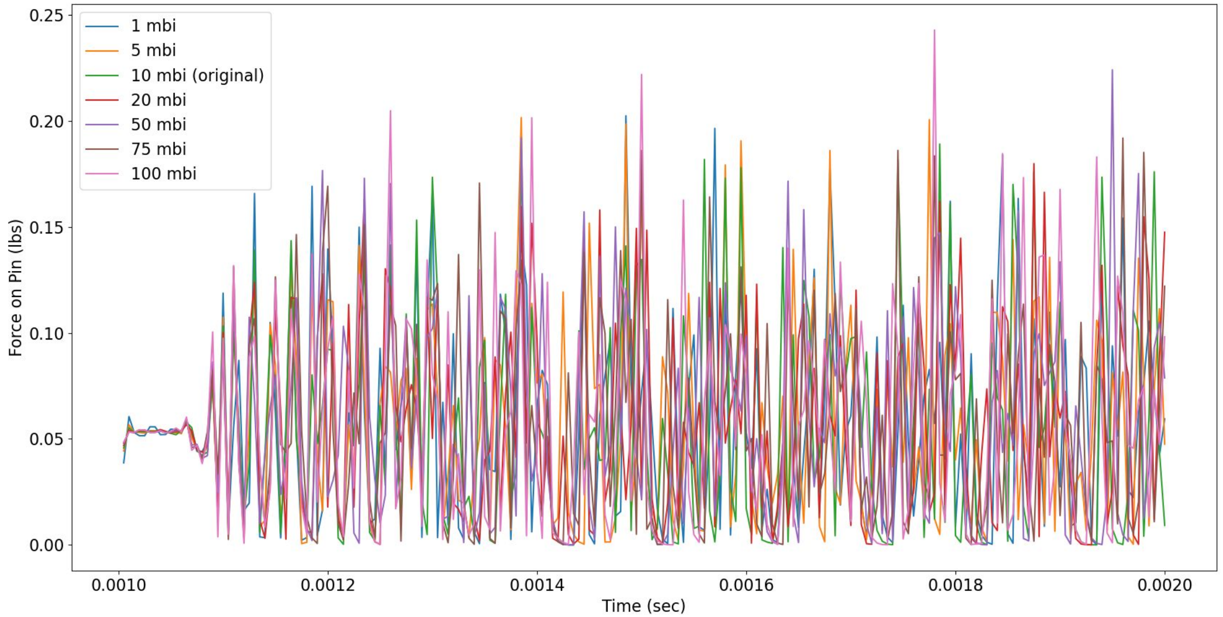


Sinusoid Displacement of Pawl (0.005 inches, +z)

- Much noisier than the +X case
- Similar story to the +X case







Pin-Pawl Idealized Model

- Haversine shock:

$$F_d = p \cdot a \cdot \sin(\frac{\pi t}{t_{shock}})^2$$

- Sinusoidal Vibration:

$$F_d = p \cdot a \cdot sin(\frac{2\pi t}{0.1e-3})$$

where p is pressure, a is pressure area

- Normal force from dynamic force F_d and seating force F_s:

$$N_{xz} = \sqrt{(F_d \sin(\theta) + F_s)^2 + (F_d \cos(\theta))^2}$$

- Regularized velocity:

$$v_{reg} = \tanh(\frac{2.5\dot{\theta} r}{v_{tol}})$$

- Friction force:

$$F_f = C_f N_{xz} r$$

where r is the pin radius, C_f is the coefficient of friction ($C_f = 0.2$)

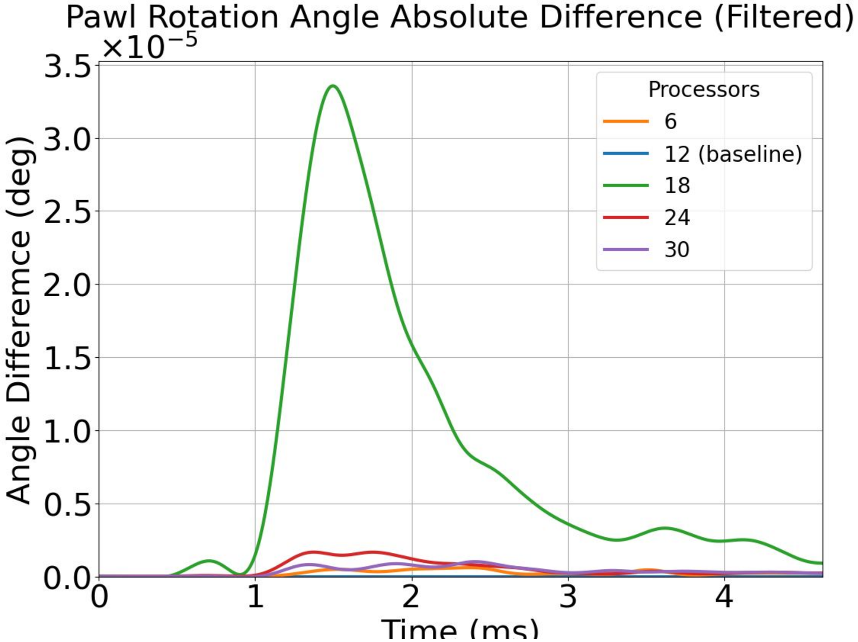
Equation of motion with l_d and l_s being dynamic and seating force distance from axis:

$$\ddot{\theta} = \frac{1}{I_{yy} + md^2}\left(F_d l_d - F_s l_s \sin(\theta) - F_f\right)$$

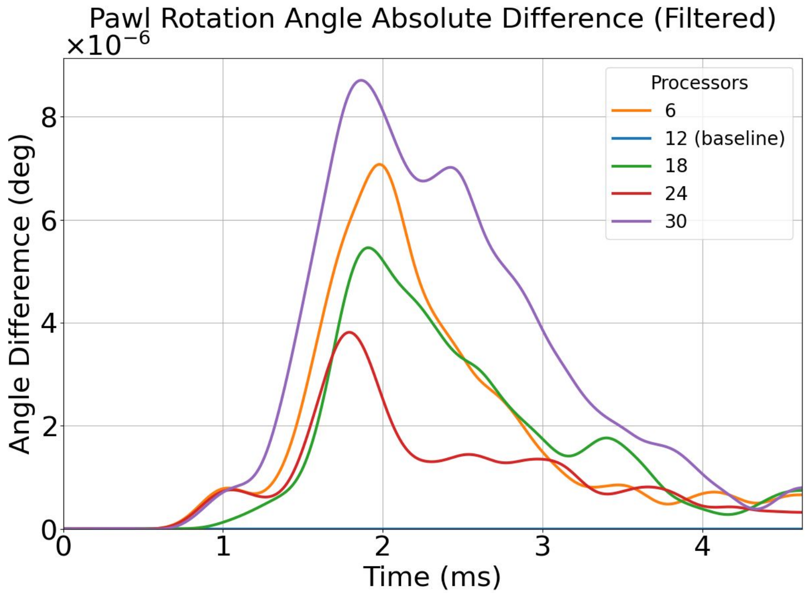
Retrieved from Sierra SM:
m = 7.47249e-07 lb
I_{yy} = 5.01218e-09 lb in s^2
l_d = 0.10883 in
l_s = 0.0975 in
d = 0.01181 in
F_s = 0.612 lb
r = 0.0201 in
v_{tol} = 16 in/s
p = 100 lb/in^2
a = 0.002191 in^2

Pin-Pawl Processor Used – Different Amplitudes (Haversine Shoc

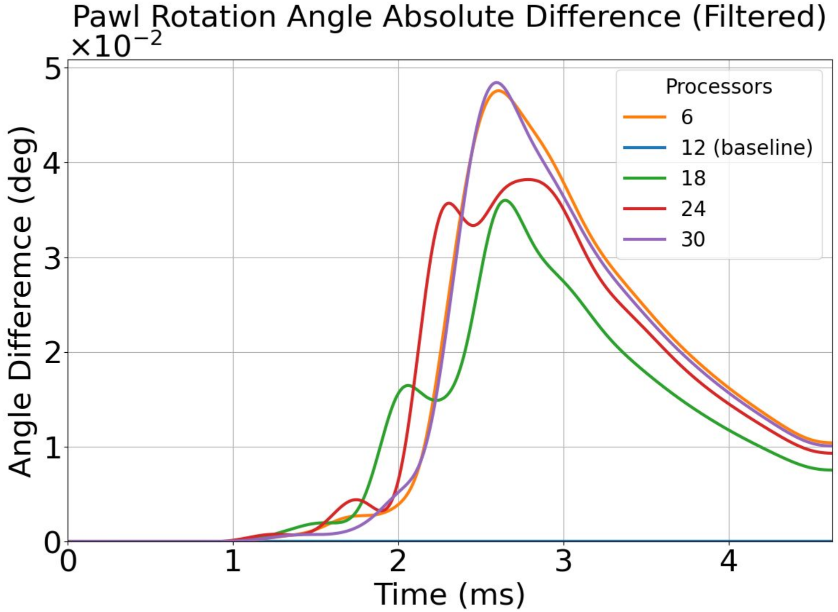
5% Force



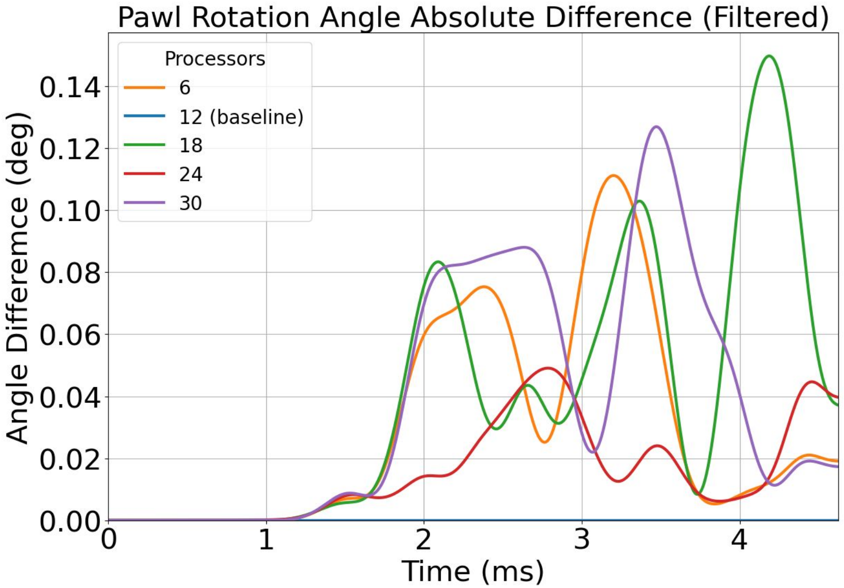
10% Force



50% Force

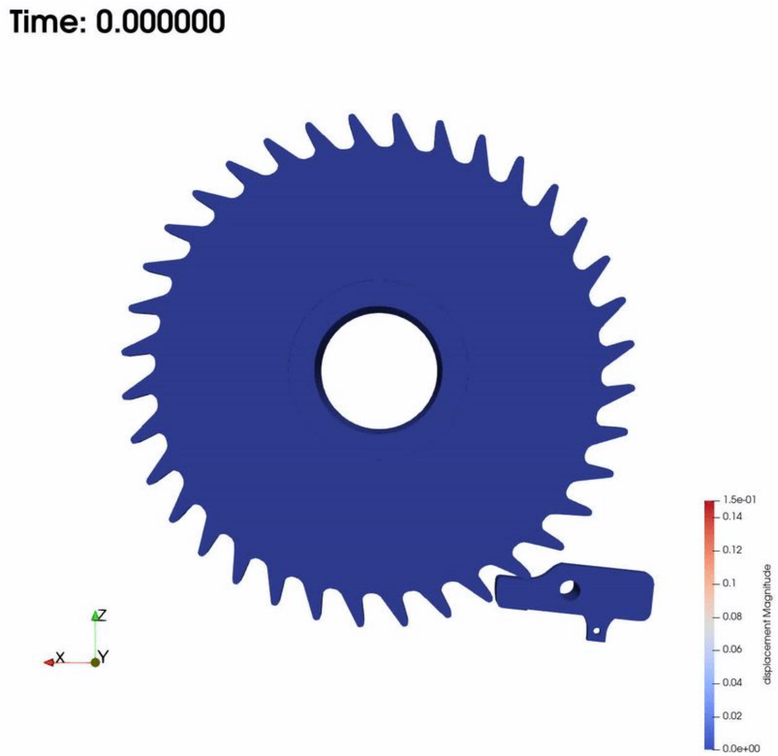


100% Force

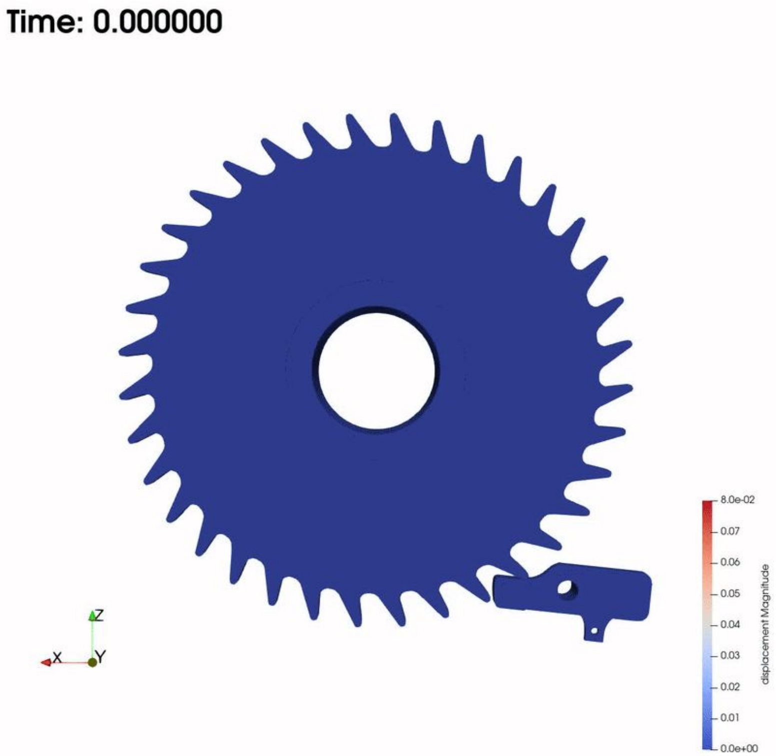


Sinusoidal Vibration Initial Tests (Vibration Amplitude Study)

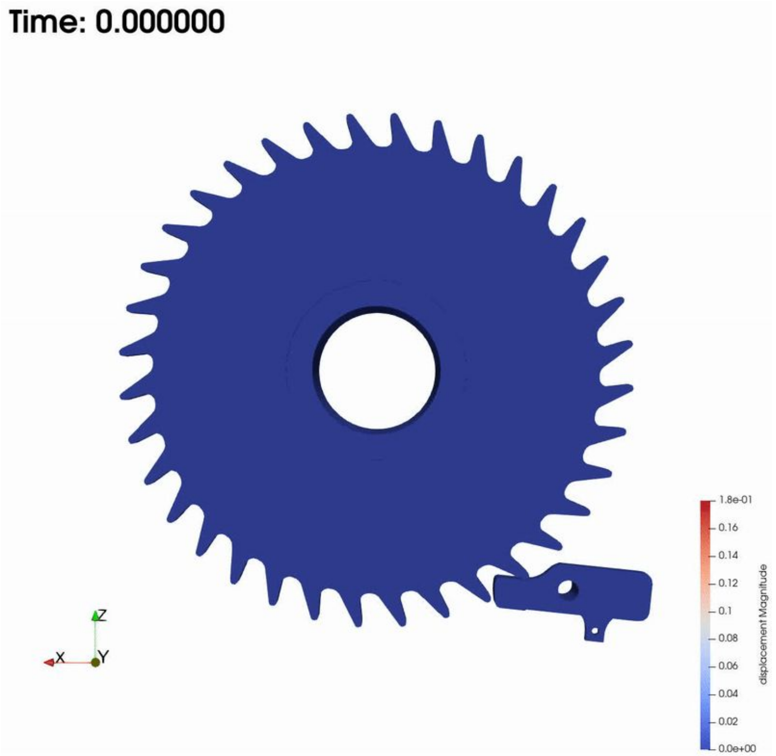
- 0.005in selected for prescribed displacement
- 0.5f pseudo force too small



SINE_MOM_10000freq_-**0.001in**_0.5f_0.5ms_100%_10mbi_cee-compute005-128



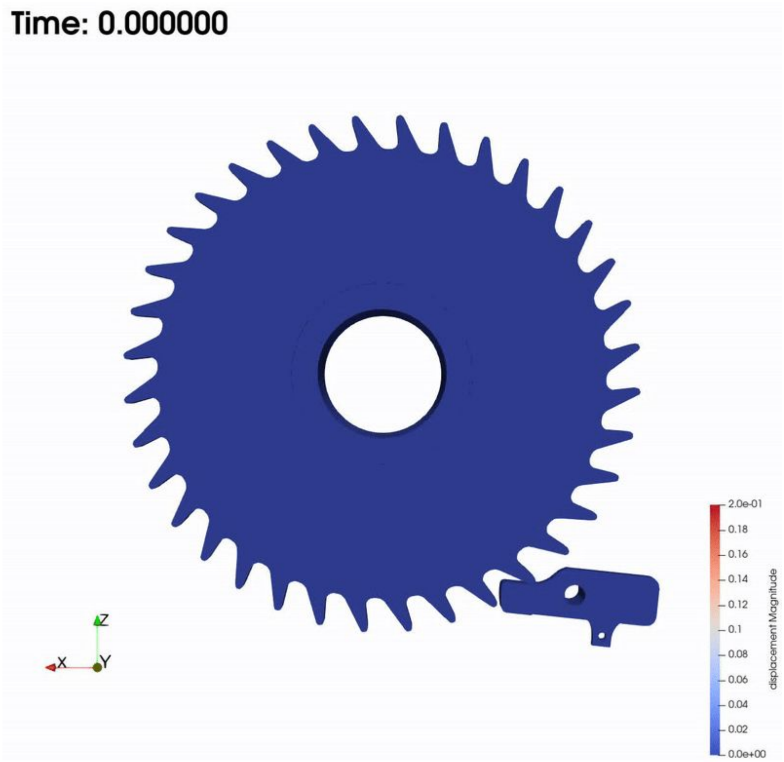
SINE_MOM_10000freq_-**0.025in**_0.5f_0.5ms_100%_10mbi_cee-compute005-128



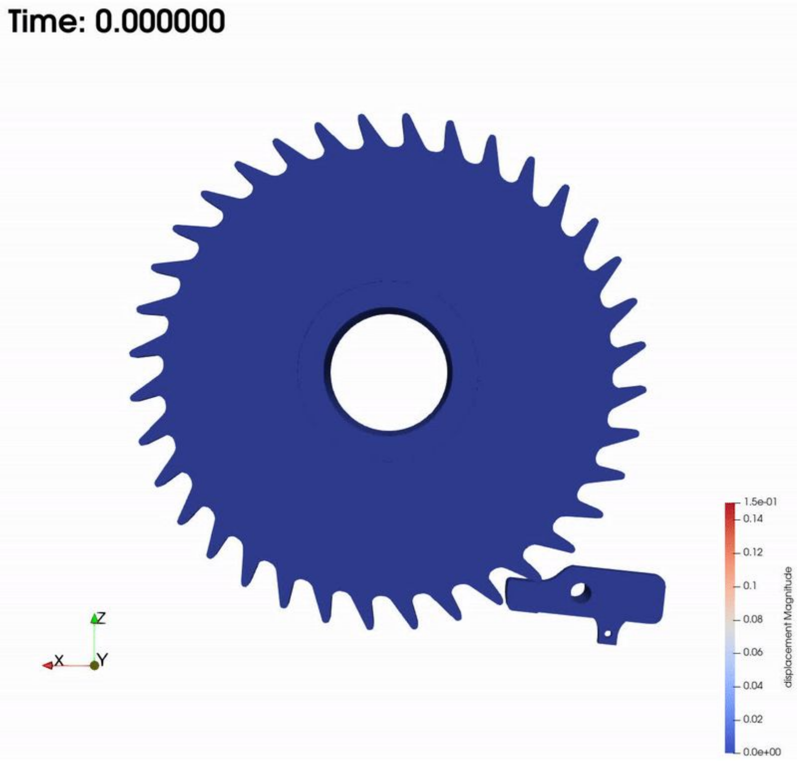
SINE_MOM_10000freq_-**0.005in**_0.5f_0.5ms_100%_10mbi_cee-compute005-128

Sinusoidal Vibration Initial Tests (Pseudo Force Study)

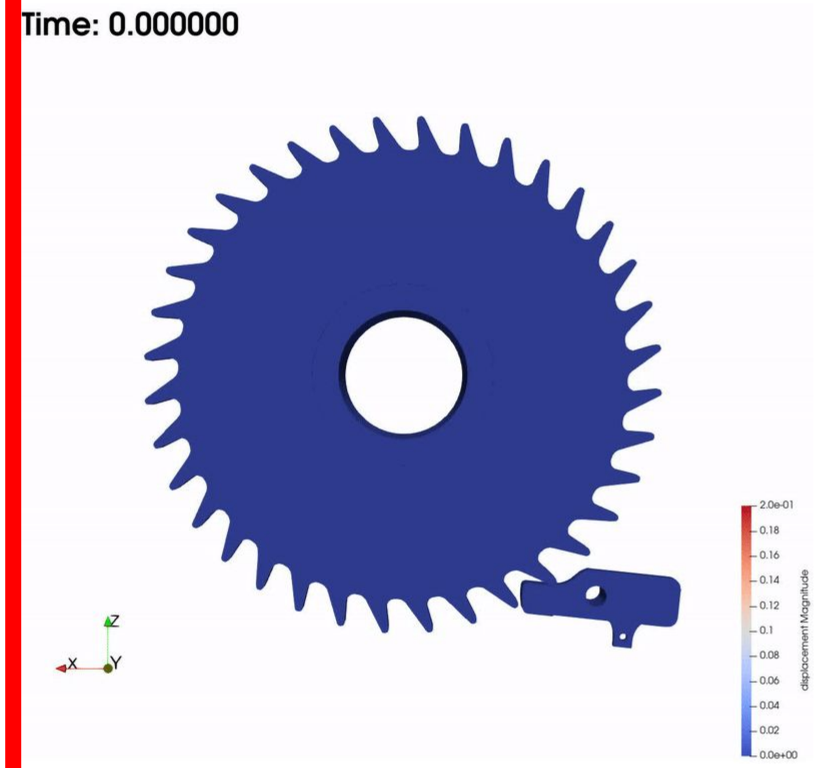
- 13.0f pseudo force selected



SINE_MOM_10000freq_-0.005in_**1.0f**_0.5ms_100%_10mbi_cee-compute001-128



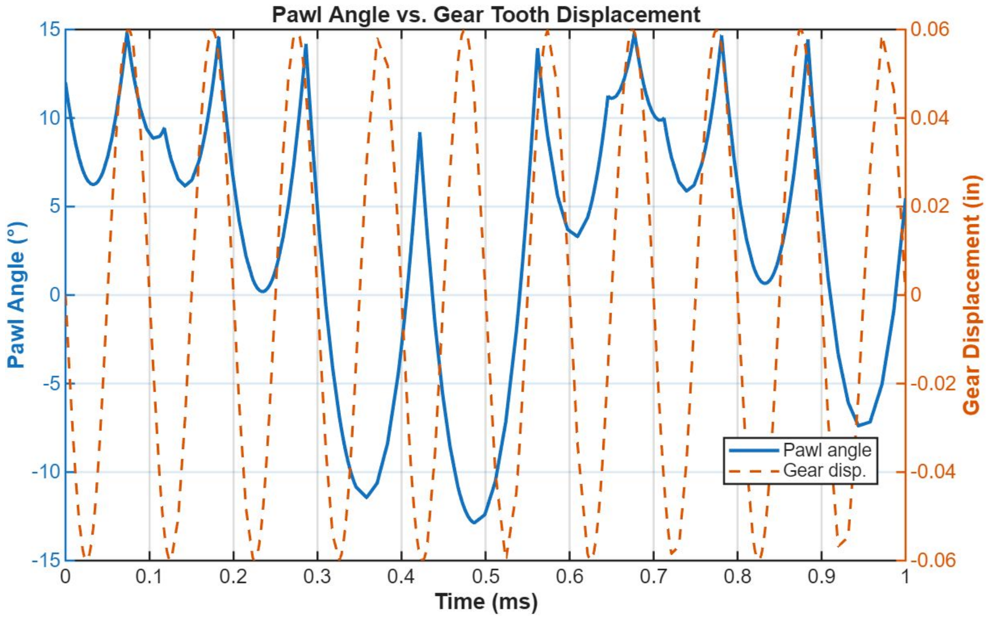
SINE_MOM_10000freq_-0.005in_**25.0f**_0.5ms_100%_10mbi_cee-compute001-128

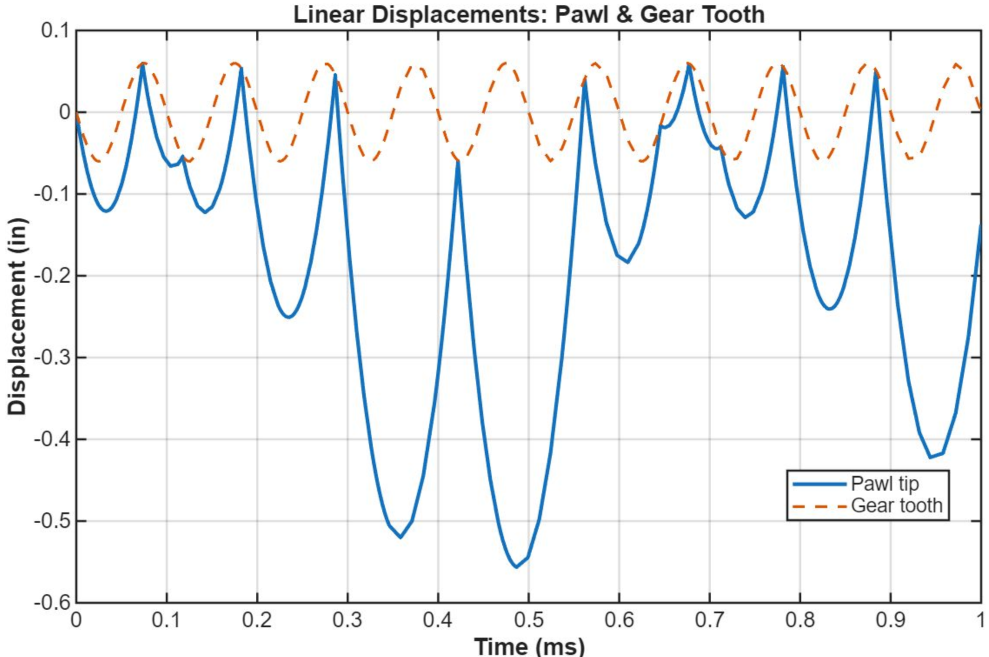


SELECTED_SINE_MOM_10000freq_-0.005in_**13.0f**_0.5ms_100%_10mbi_cee-compute001-128

Pawl – Gear Idealized Model – Sinusoidal Vibration MATLAB

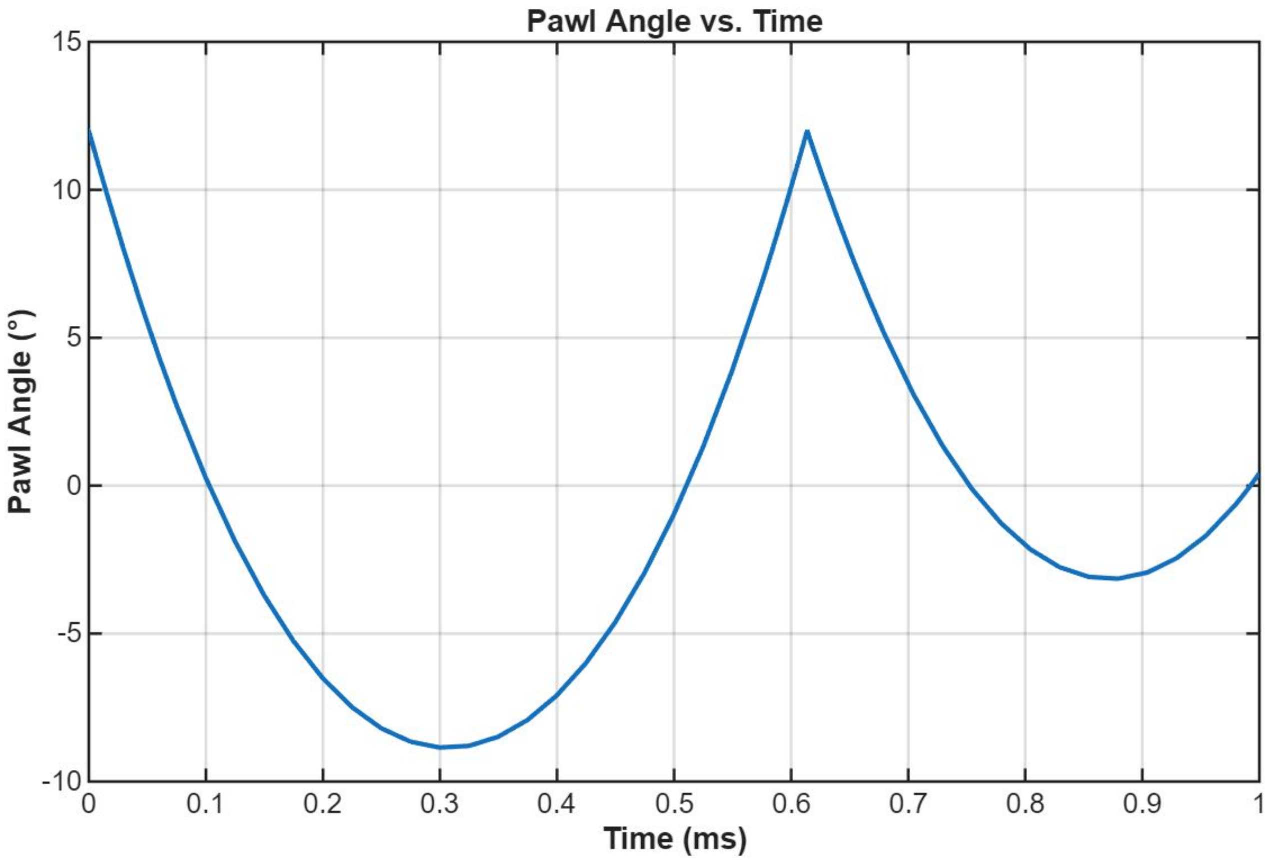
```
%% ── PARAMETERS ──────────────────────────────────────────────
mass         = 0.7e-06;    % [slug]      Pawl inertia
penalty_k    = 7e20;       % [lbf/ft]    Penalty spring stiffness
penalty_c    = 8e05;       % [lbf·s/ft]  Penalty damping coefficient
x            = 0.10;       % [ft]        Moment arm (pivot to contact)
pseudo_force = 13;         % [lbf]       Constant pseudo-force

A      = -0.005;           % [ft]        Gear sinusoid amplitude
f      = 1e4;              % [Hz]        Gear sinusoid frequency
omega  = 2*pi*f;           % [rad/s]     Gear sinusoid angular frequency
tf     = 1e-3;             % [s]         Total simulation time

%% ── ODE DEFINITION ──────────────────────────────────────────
% State s = [y; v], where y = pawl tip disp [ft], v = velocity [ft/s]
odefun = @(t, s) [ ...
    s(2); ...
    ( pseudo_force + ...
      ( (s(1) - A*sin(omega*t)) > 0 ) .* ( ...
        -penalty_k*(s(1) - A*sin(omega*t)) ...
        - penalty_c*(s(2) - A*omega*cos(omega*t)) ) ...
    ) / mass ...
];

%% ── RUN SIMULATION ──────────────────────────────────────────
[t, S] = ode45(odefun, [0 tf], [0; 0]);
t_ms   = t * 1e3;          % [ms]

%% ── DATA PREPARATION ────────────────────────────────────────
pawl_disp_in = S(:,1) * 12;          % [in]
gear_disp_in = A * sin(omega*t) * 12; % [in]
angle_deg    = 12 + atan2(S(:,1), x) * (180/pi); % [°]
```





Pawl – Gear Idealized Model – Haversine Shock MATLAB

```
%% —— PARAMETERS ——————————————————————————————————————————————
mass         = 8.8235e-07;   % [slug]      Pawl inertia
penalty_k    = 4.2857e20;    % [lbf/ft]    Penalty spring stiffness
penalty_c    = 1.9538e06;    % [lbf·s/ft]  Penalty damping coefficient
x            = 0.007;        % [ft]        Moment arm (pivot to contact)
pseudo_force = 0.05;         % [lbf]       Constant pseudo-force
hav_v0       = 20;           % [ft/s]      Initial downward velocity
tf           = 1e-3;         % [s]         Total simulation time

%% —— ODE DEFINITION ——————————————————————————————————————————
% State s = [y; v], where y = pawl tip disp [ft], v = velocity [ft/s]
odefun = @(t, s) [ ...
    s(2); ...
    ( pseudo_force + (s(1) > 0) .* ( ...
        -penalty_k * s(1) ...
        - penalty_c * s(2) ) ...
    ) / mass ...
];

%% —— RUN SIMULATION ——————————————————————————————————————————
[t, S] = ode45(odefun, [0 tf], [0; hav_v0]);
t_ms    = t * 1e3;              % [ms]

%% —— ANGLE CALCULATION ———————————————————————————————————————
angle_deg = 12 + atan2(S(:,1), x) * (180/pi); % [°]
```



Quantifying the Effect of Non-Physical Parameters on the Nonlinear Dynamics of an Electromechanical Ratcheting Mechanism

Students: *Shunsuke Winston, Alan Pham, and Brennan Bahr*

Mentors: Aabhas Singh, Rob Flicek, Rob Kuether, Kumar Vemaganti, Scott Grutzik, and Chris Schumann

Problem Statement

The finite element model of a complex system such as a ratcheting mechanism has been known to be sensitive to small changes in non-physical parameters such as momentum balance iteration and mesh discretization. This work seeks to find the effects of change in these non-physical parameters on the response of finite element sub-models of a ratcheting mechanism.

Approach/Methodology

The stop pawl assembly is divided into three simpler sub-models. For each sub-model, three non-physical parameters are changed: momentum balance iteration, mesh density and number of processors used. Each parameter is tested with two environments: haversine shock and sinusoidal vibration. To run these tests Sandia's Sierra SM was used for the finite element software.

Key Results

Each sub-model exhibited different response to change in the non-physical parameters. The pin-spring-pawl model showed convergence for all parameters, whereas the pin-pawl model showed no convergence for all parameters and chaotic behavior surrounding the contact and friction. The pawl-gear model showed convergence for one parameter and chaotic behavior in others in specific environment.

	Pin-Spring-Pawl	Pin-Pawl	Pawl-Gear
Momentum Balance Iteration			
Mesh Density			
Processor Count			

Outcomes and Impact

The results have revealed different levels of sensitivity of the sub-models to non-physical parameters. This shows that careful consideration of these parameters are required to accurately model a ratcheting mechanism even at the sub-model level.