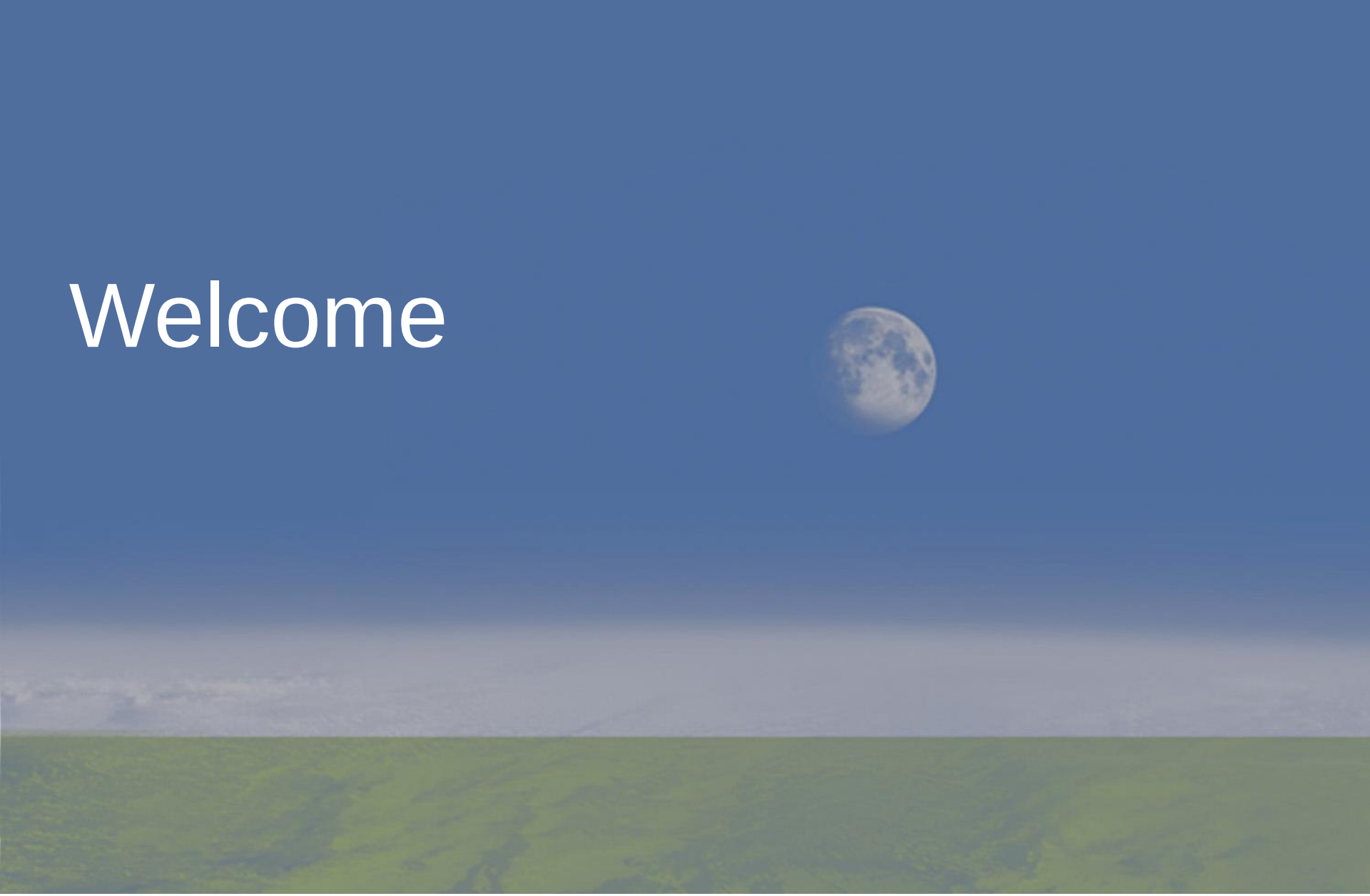
Welcome



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Dynamic Stress and Load Prediction at the Core of the Mars 2020 Percussive Drill

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Spacecraft Structures and Dynamics Group
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Presentation Outline

- Introduction
- Mars 2020 Percussion Drill Overview
- Model Details & Analysis Approach
  - *Experimental Setup*
  - *LS-DYNA FE Model*
- Results
  - *Comprehensive V&V of Model*
  - *Spring Stresses*
  - *Drive Plate Forces*
  - *Hammer Shaft Fatigue Stress*
  - *Rotary Bearing Axial Loads*
- Conclusion

Introduction

Background
NASA and the planetary exploration community is interested in collecting rock core samples from the Martian surface. To this end the Mars 2020 rover mission will use a rotary percussive core drill to collect cigar sized samples from Martian surface rocks.

Our Goal
Provide the Mars 2020 drill development team with a predictive and design-driving analysis support

Method:
Use the LS-DYNA FEA code to examine loads and stresses in different drill components

Mars 2020 Percussion Drill Overview

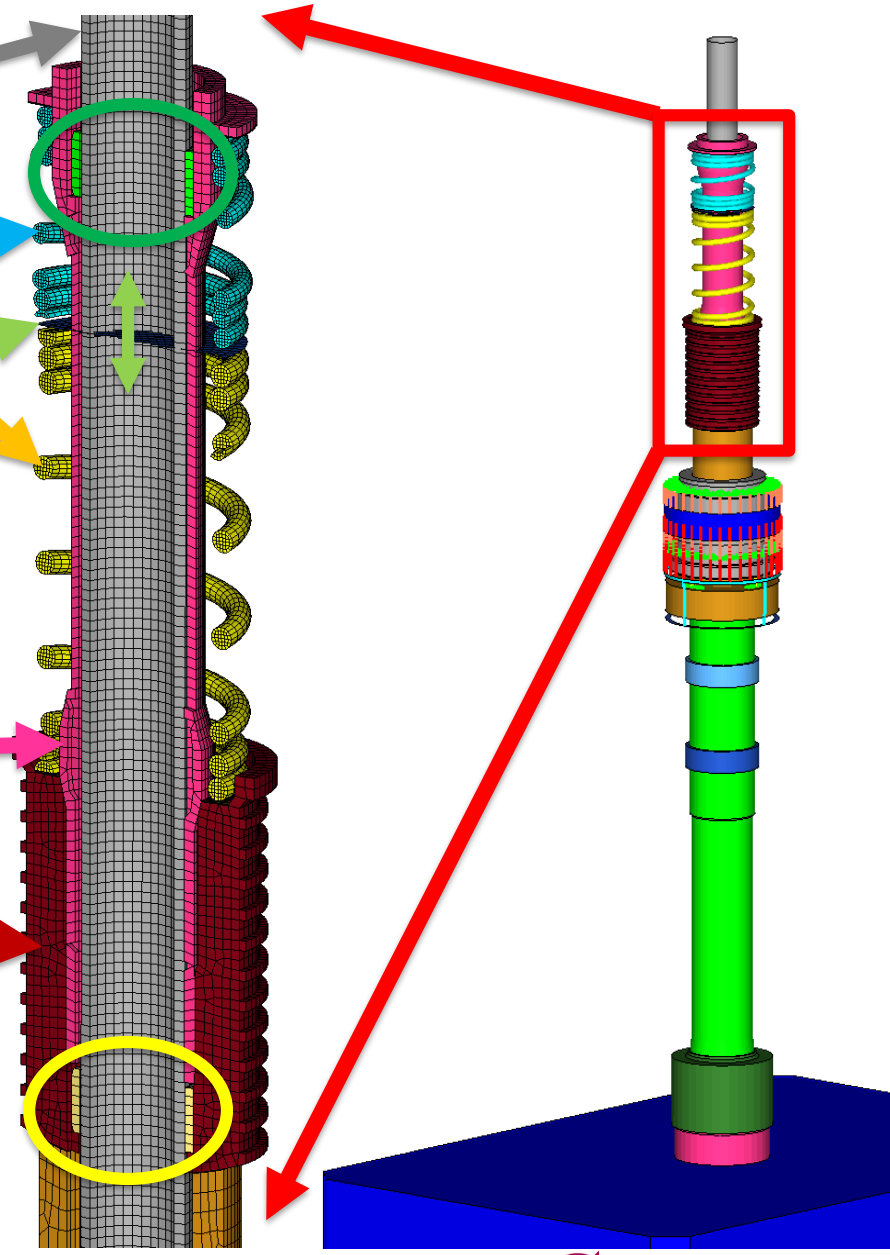
- The sample coring drill is a rotary percussive drill designed to extract rock core samples from the surface of Mars
- Impact loading on the bit allows the rock to be efficiently chipped off the surface rather than ground off by friction (bad for bit life)
- Bit is a hollow, metallic, cylindrical structure that pulverizes a ring of rock about the axis of the bit
- Drilling creates a cylinder of rock within the bit's hollow center
- Core sample extracted for later analysis

Image from
CORE ACQUISITION AND CACHING FOR THE 2020 MARS MISSION.
44th Lunar and Planetary Science Conference (2013)
K. Zacny1 , P. Chu2 , G. Paulsen1 , J. Craft3

Current FEM Overview - Top

<u>Hammer & Drive Spring Assembly</u>

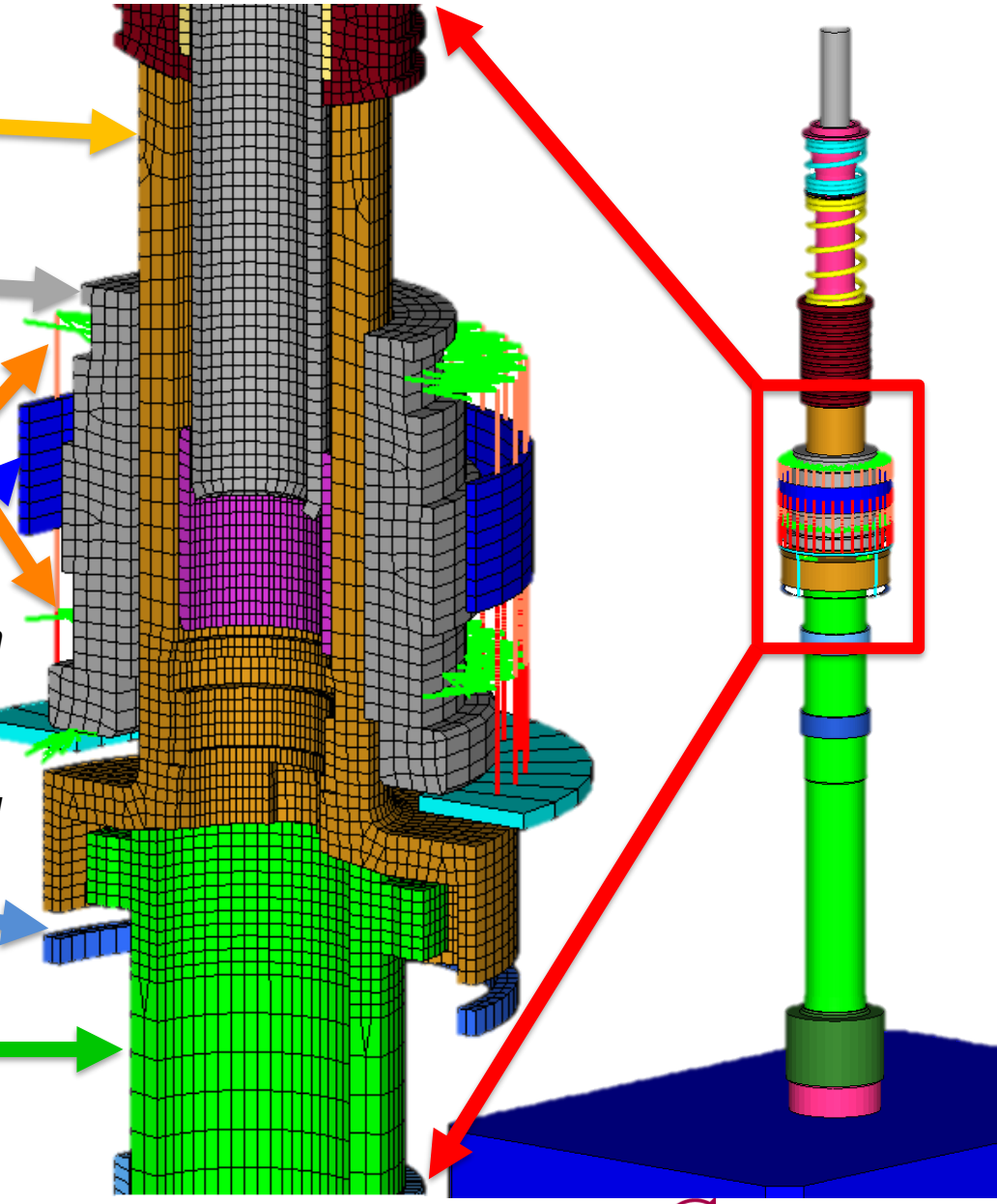
- *Cantilevered Guide Shaft*
  - ✓ *Aligns hammer assembly and anvil*
- *Drive Springs*
  - ✓ *Thru-thickness stresses recovered*
- *Drive Plate*
  - ✓ *Prescribed sine wave motion excites harmonic hammer motion*
- *Bushings*
  - ✓ *Slide on central shaft and guide hammer onto Anvil*
- *Hammer Shaft*
  - ✓ *Connects hammer head to springs*
- *Hammer Head*
  - ✓ *Source of impact loads that travel down through the drill: Impacts on Anvil*



Current FEM Overview - Middle

<u>Anvil-Bit-Drill Body Interfaces</u>

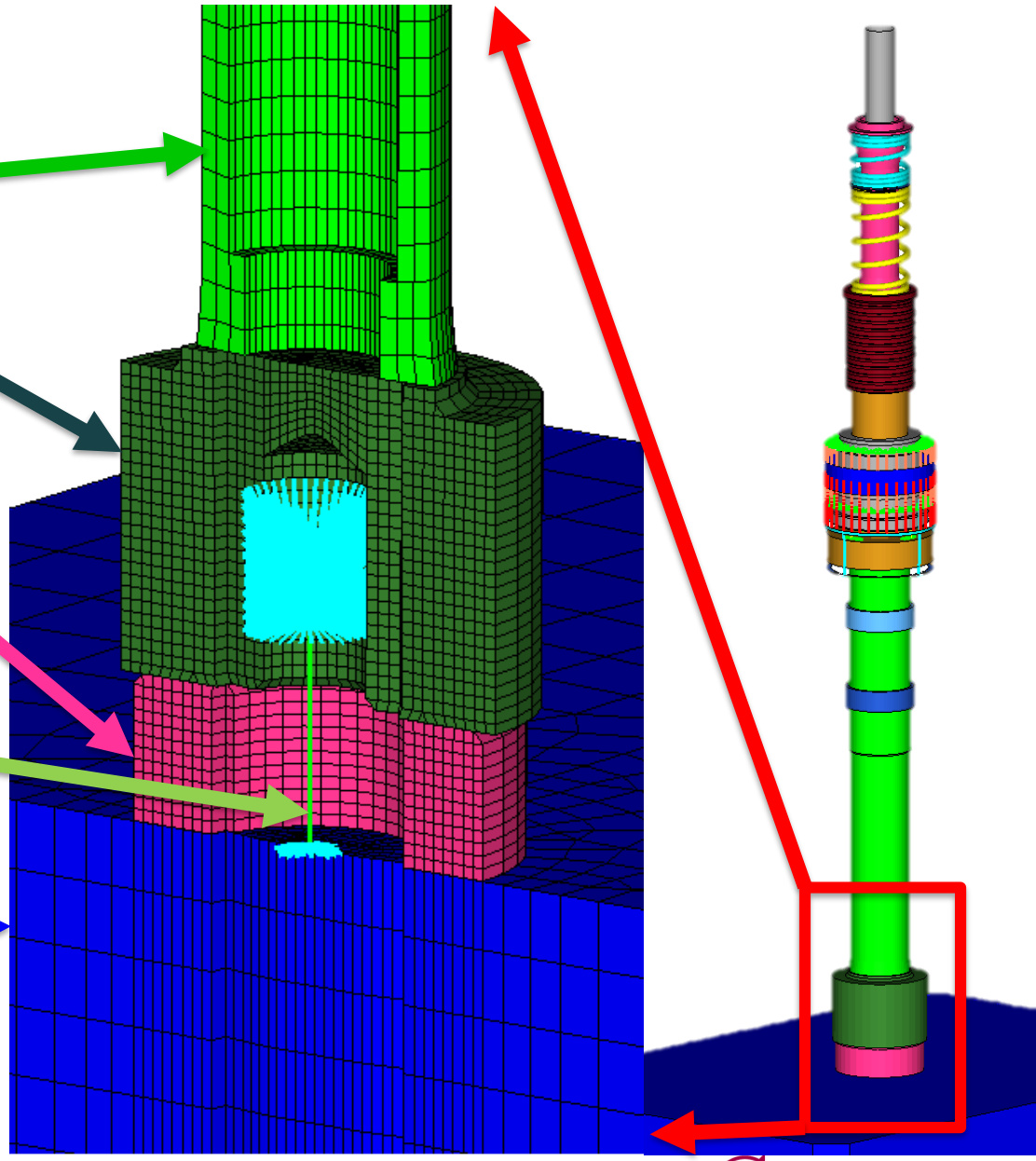
- *Anvil*
  - ✓ *Transfers percussion and rotational drive loads to bit*
- *Anvil Load Ring*
  - ✓ *Preload and interface between drill body and anvil*
- *Bearings*
  - ✓ *Transmits preload to anvil and bit*
- *Drill Body Lumped Mass*
  - ✓ *6 kg mass simulates drill body reaction to reflected percussion loads*
- *Drill Assembly Mass/Ground*
  - ✓ *Compliant spring connection to ground*
- *Anvil Hard Stop*
  - ✓ *Soft stop contact in case of no-bit percussion event*
- *Lab Bit*
  - ✓ *Accepts impact loads from anvil*



Current FEM Overview - Bottom

<u>Bit to Lab Setup (Simulated Impact surface) Components</u>

- *Lab Bit*
  - ✓ *Flat end, no teeth, impacts against LCC*
- *Load Cell Cap (LCC)*
  - ✓ *Simulated rock and provides preload interface to load cell*
- *Load Cell (LC)*
  - ✓ *Measures percussion load*
- *Preloaded Bolt*
  - ✓ *Applies a 30 kN preload to LC during simulation preload phase*
- *Lab Base*
  - ✓ *Heavy steel base, grounded at each of 4 corners*



Verification and Validations

Numerical Verifications

- ✓ *Solvers and Setting Sensitivity*
- ✓ *Mesh Sensitivity and Convergence*

Kinematic Validation

- ✓ *Drive plate and Hammer motion confirmed to match well with test data (not shown) and Simulink model*

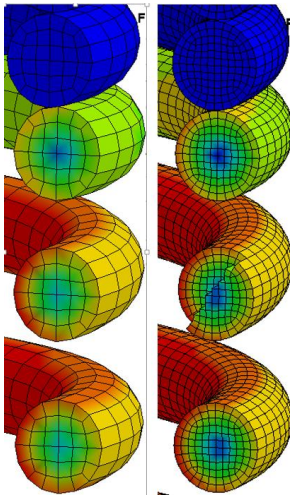
Loads Validation

- ✓ *Percussion loads at LC match very well with model across impact velocity range*
- ✓ *Spring model validated and calibrated using test data*
- ✓ *LC damping calibrated against experimental vibration decay rate*

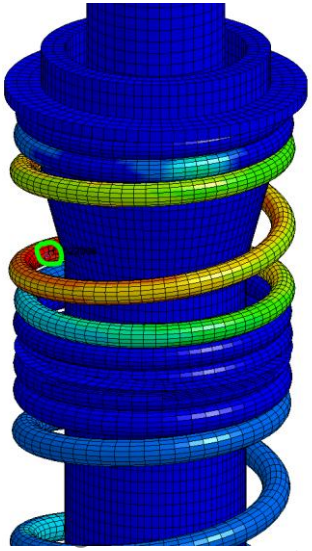
Stress Validation

- ✓ *Thru-thickness stresses recovered*
- ✓ *Static spring stresses match model predicted spring stresses*

Mesh effects on 3D solid meshed springs

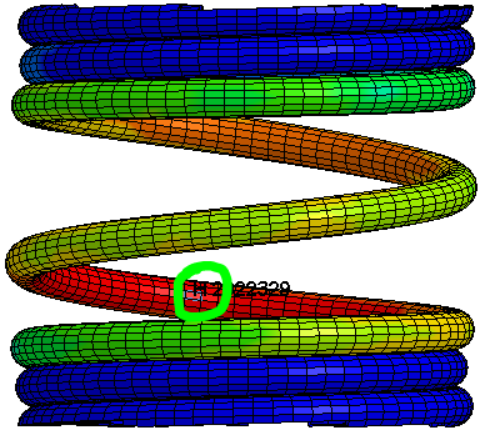


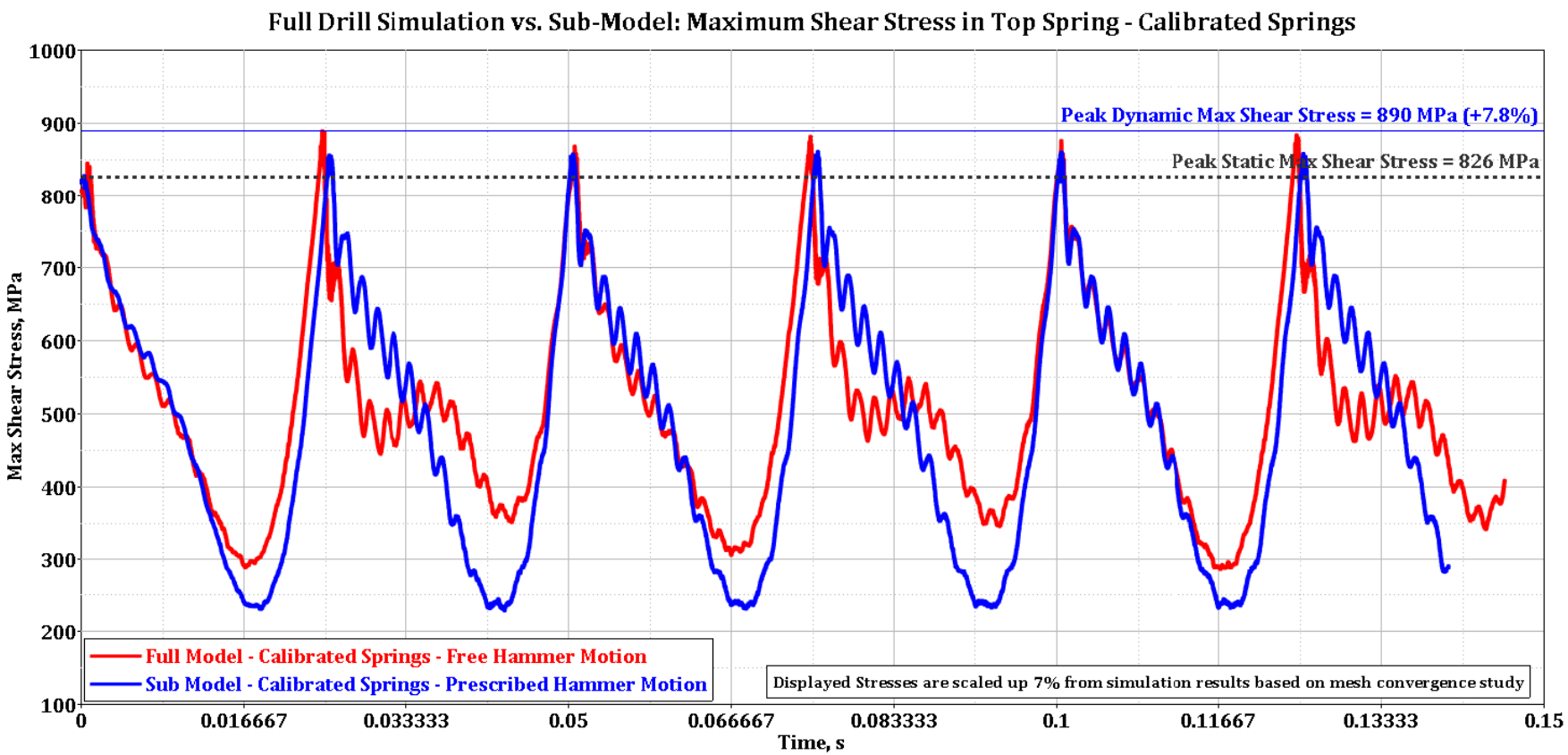
Model predicts peak dynamic spring stresses in same location as previous spring failures



Drive Spring Stresses – Top Spring

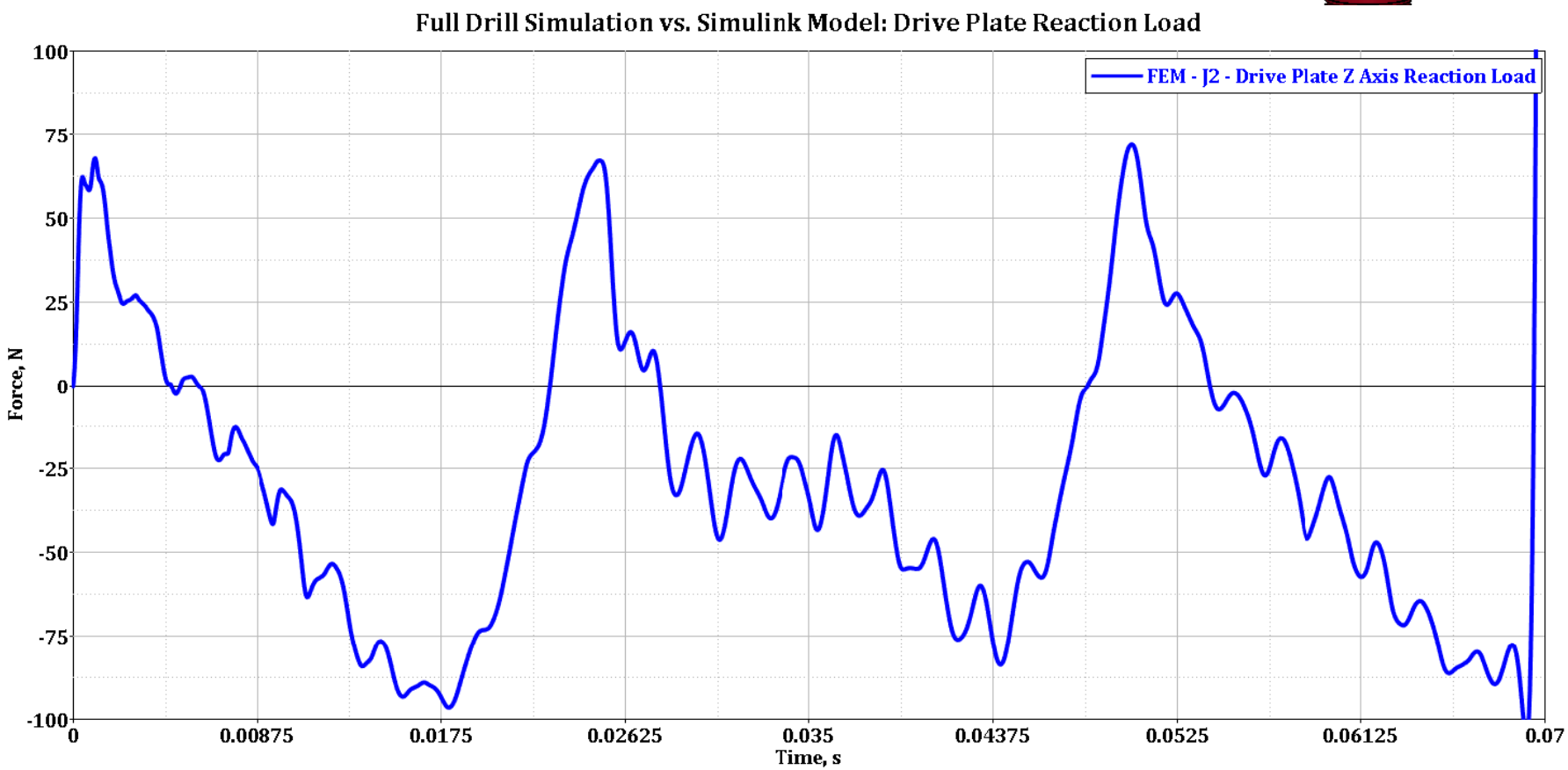
Drive spring stresses were found to be 7.8% higher than static predictions and similar for the full drill model and a quicker running sub-model





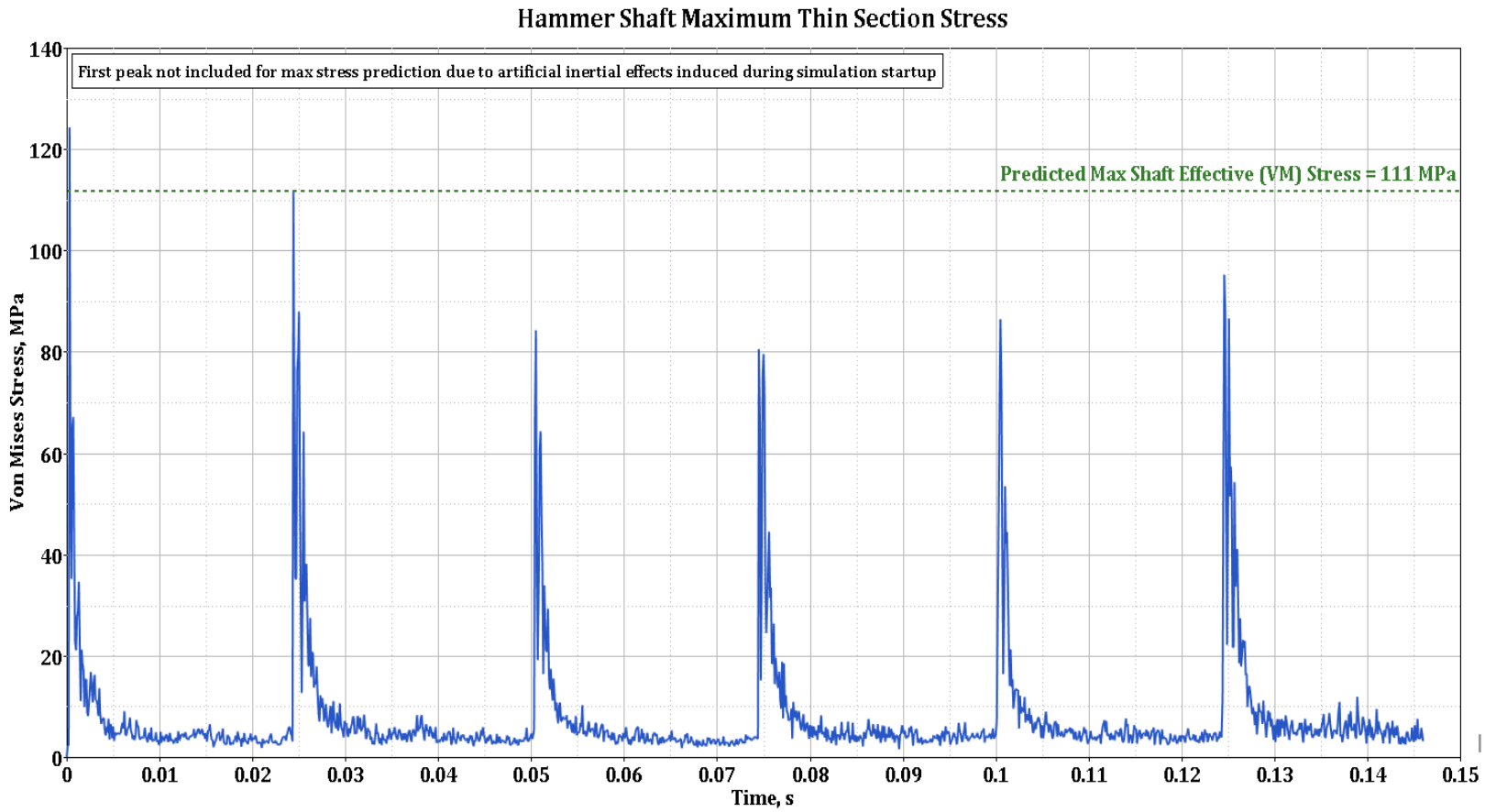
Drive Plate Forces

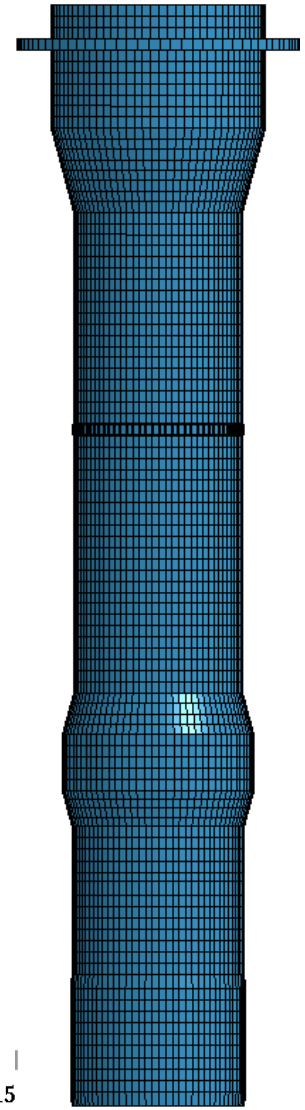
Drive plate forces are a harmonic load source to the turret, although the motion is sinusoidal, the force response is not.



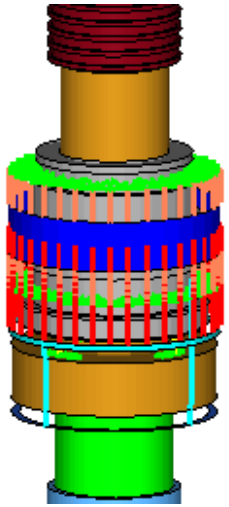
Hammer Shaft Stress

For fatigue stress reasons the dynamic stress in the hammer shaft is important: Peak-to-peak Von-Mises stress amplitude was 212 MPa, mean stress was 5 MPa at 40 Hz.



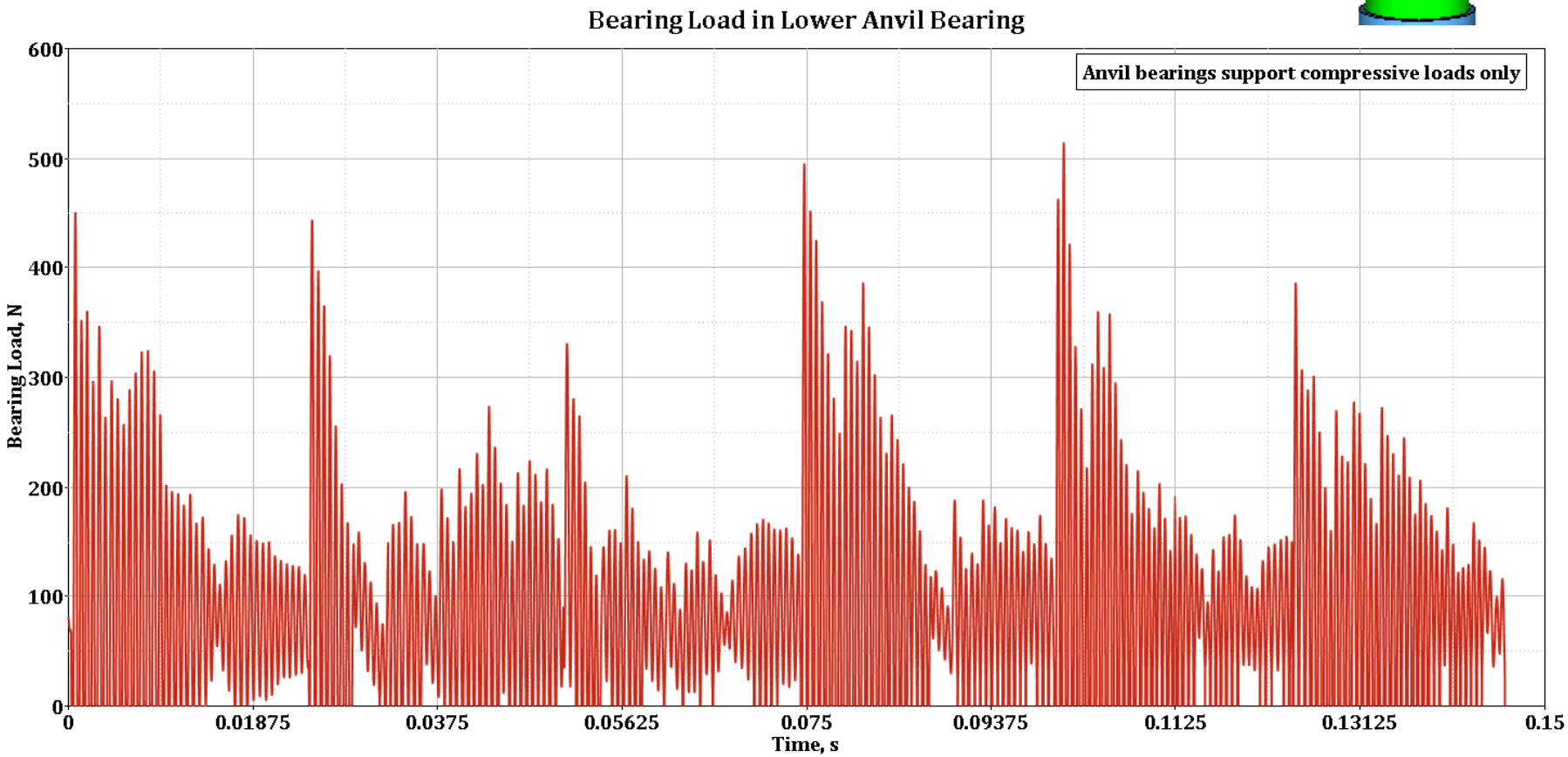


Rotary Bearing Loads



Correctly sizing the load capacity of the bearings based on percussive loading is critical to bearing life.

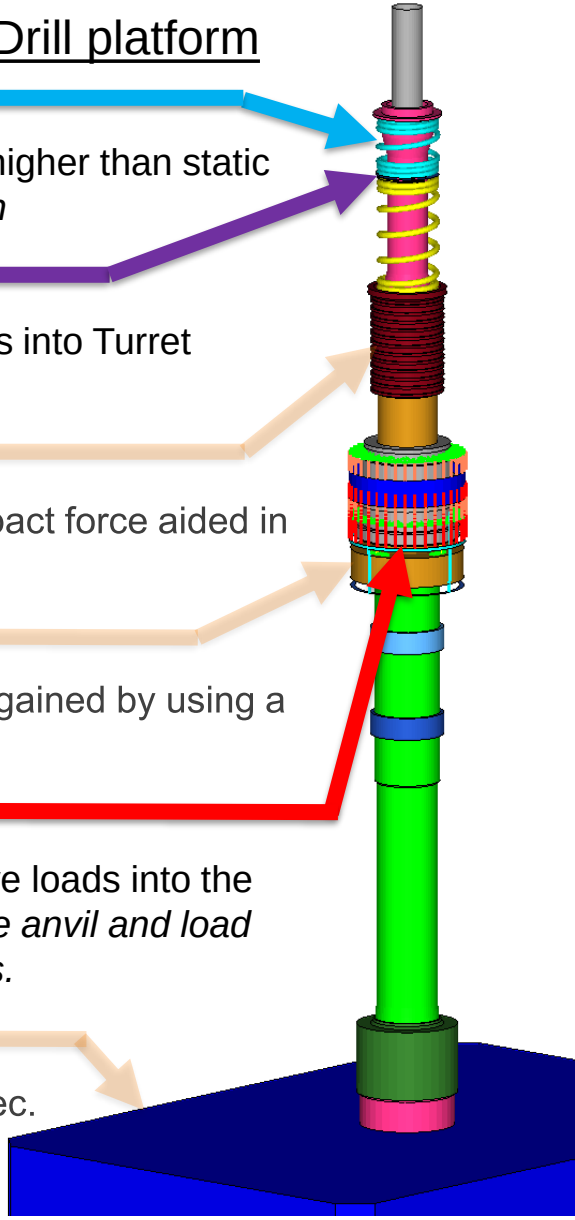
Maximum bearing load was approximately 500 N for both anvil bearings. The bottom bearing experiences static weight-on-bit loads



Summary of Analysis Inputs at the Drill Core

Dynamic analysis advises and drives many aspects of the Drill platform

1. *Robust Spring Sizing*
   - Peak dynamic spring stress due to impact was found to be 7.8% higher than static predictions: *Springs are being redesigned for higher stress margin*
2. *Turret Reaction Loads*
   - Reaction loads at drive plate and bearings advise forcing functions into Turret Dynamics model: -75 N to +100 N Sawtooth wave
3. *Hammer Shape and Size*
   - Extensive parametric studies on hammer shape and mass vs. impact force aided in hammer size and shape selection
4. *Anvil Length*
   - Impedance matching study determined higher impact loads were gained by using a heavier/longer anvil: *Team has moved to longer anvil design*
5. *Bearing Loads & Anvil Preload Spring*
   - Rebounding impact loads on the anvil load ring imparted excessive loads into the bearings: *Design changed to include a preload spring between the anvil and load ring to improve percussion performance and reduce bearing loads.*
6. *Experimental Setup Sizing*
   - Base plate thickness sized via analysis and verified with vendor rec.



Conclusion

We are using LS-DYNA to model and uncover the transient dynamic environment of the 2020 sample coring percussion drill

The model has passed through an extensive multi-faceted V&V approach providing the team confidence in the model output

Both stress and loads are recovered from critical areas of the drill that without analysis would be very hard to characterize.

The modeling effort is ongoing and model fidelity continues to increase.

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Thank you

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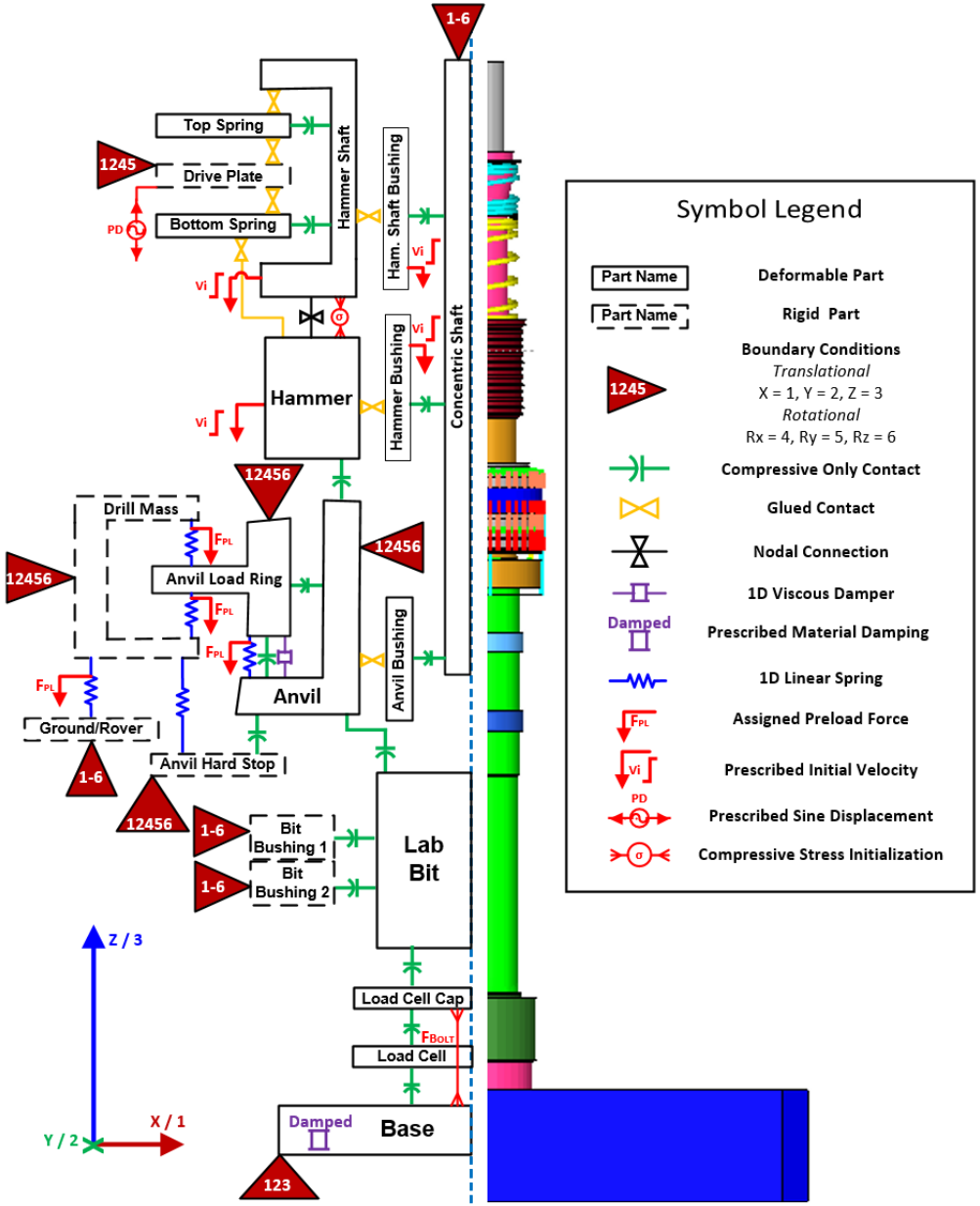
Backup – Drill Block Diagram