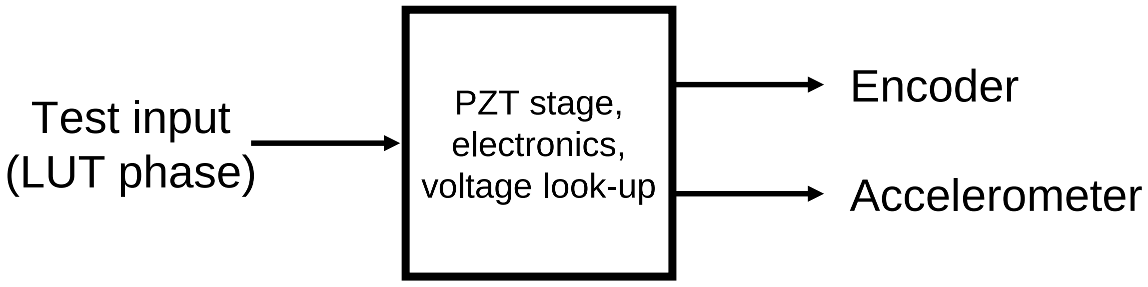
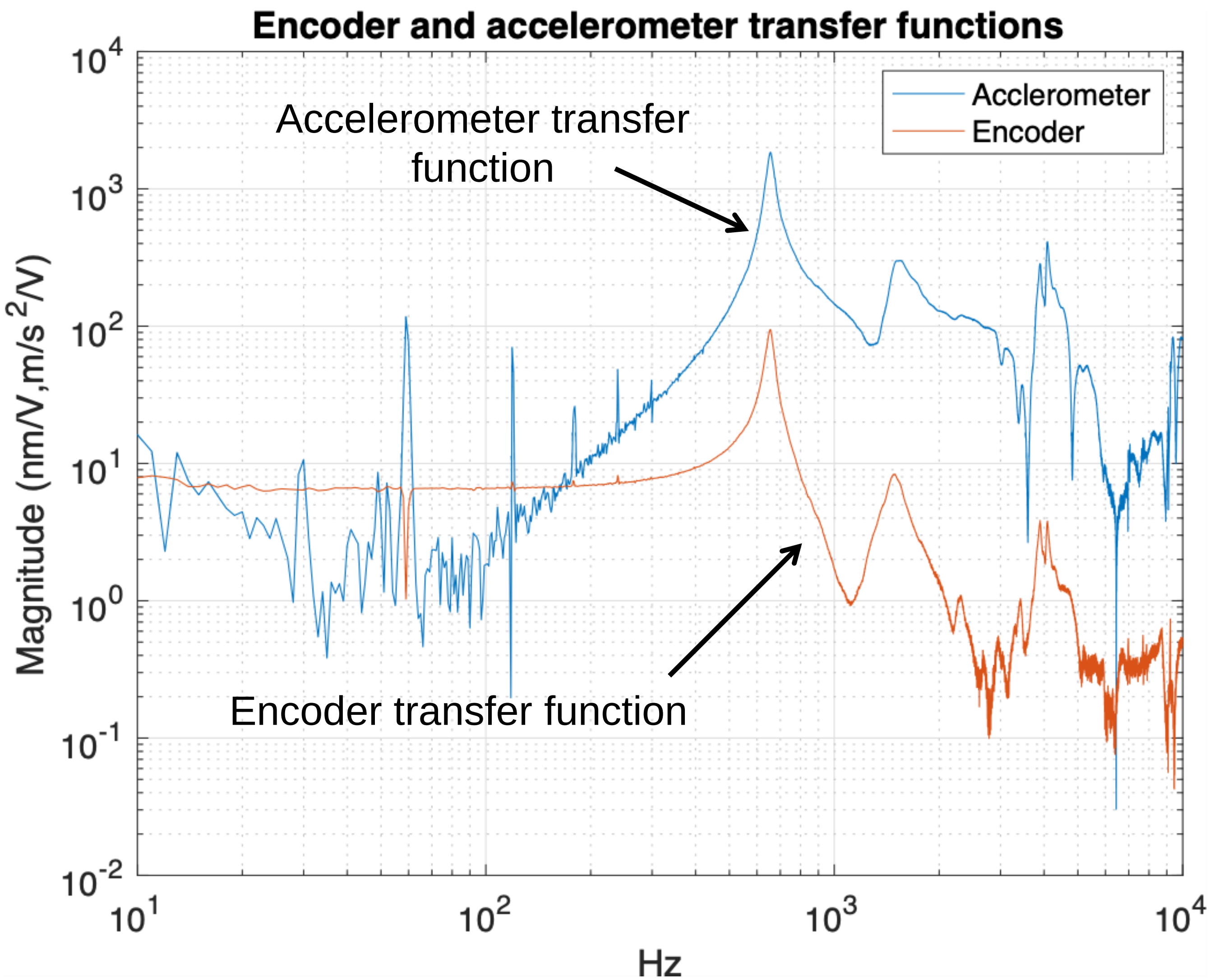
Nanometer motion control project - Feb 20, 2020

Background:

- The 4 PZT voltages are periodic when performing a complete "step"
- The voltages are specified in a look-up table whose input is a "phase"
- Constraining the phase to narrow range moves the stage about a nominal point but with much smaller stroke than a complete step
- The stage responds as a linear system in this operating scenario
- The empirical frequency response estimates are shown with this mode of operation
- In addition to the built-in stage encoder, an accelerometer is also mounted to the stage



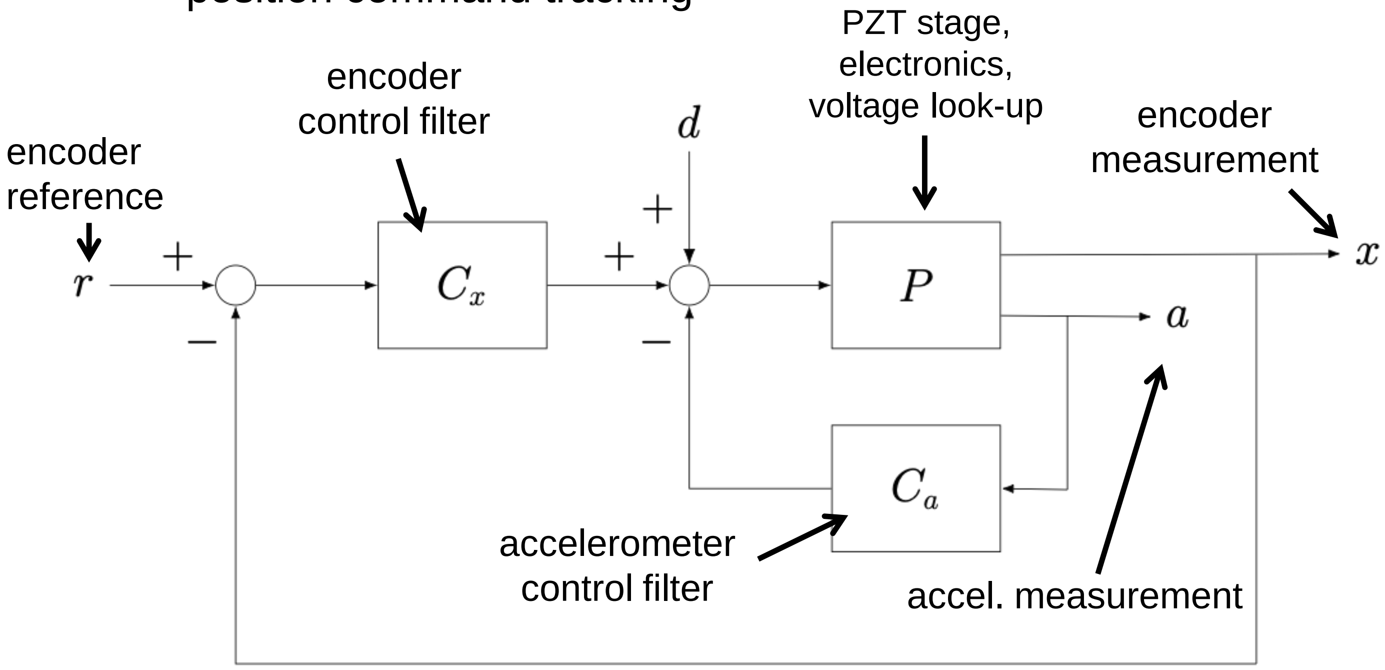


Observations:

- In addition to high frequency resonances, the stage displacement roles off below 1 kHz
- Provides insight in the fundamental limitations of the stage capability
- Accelerometer measurement is necessary to dampen main resonance near 650 Hz

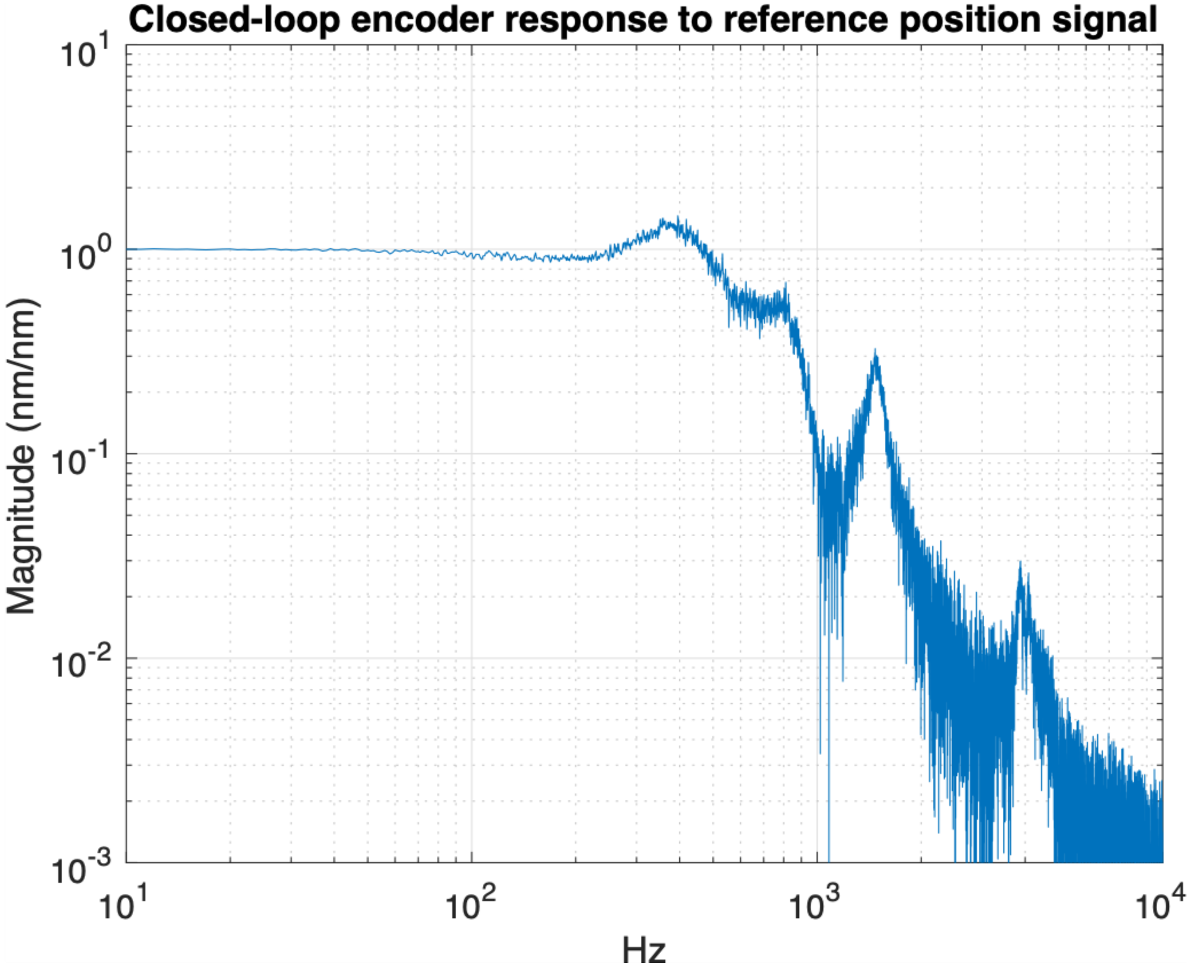
Closed-loop control of stage position

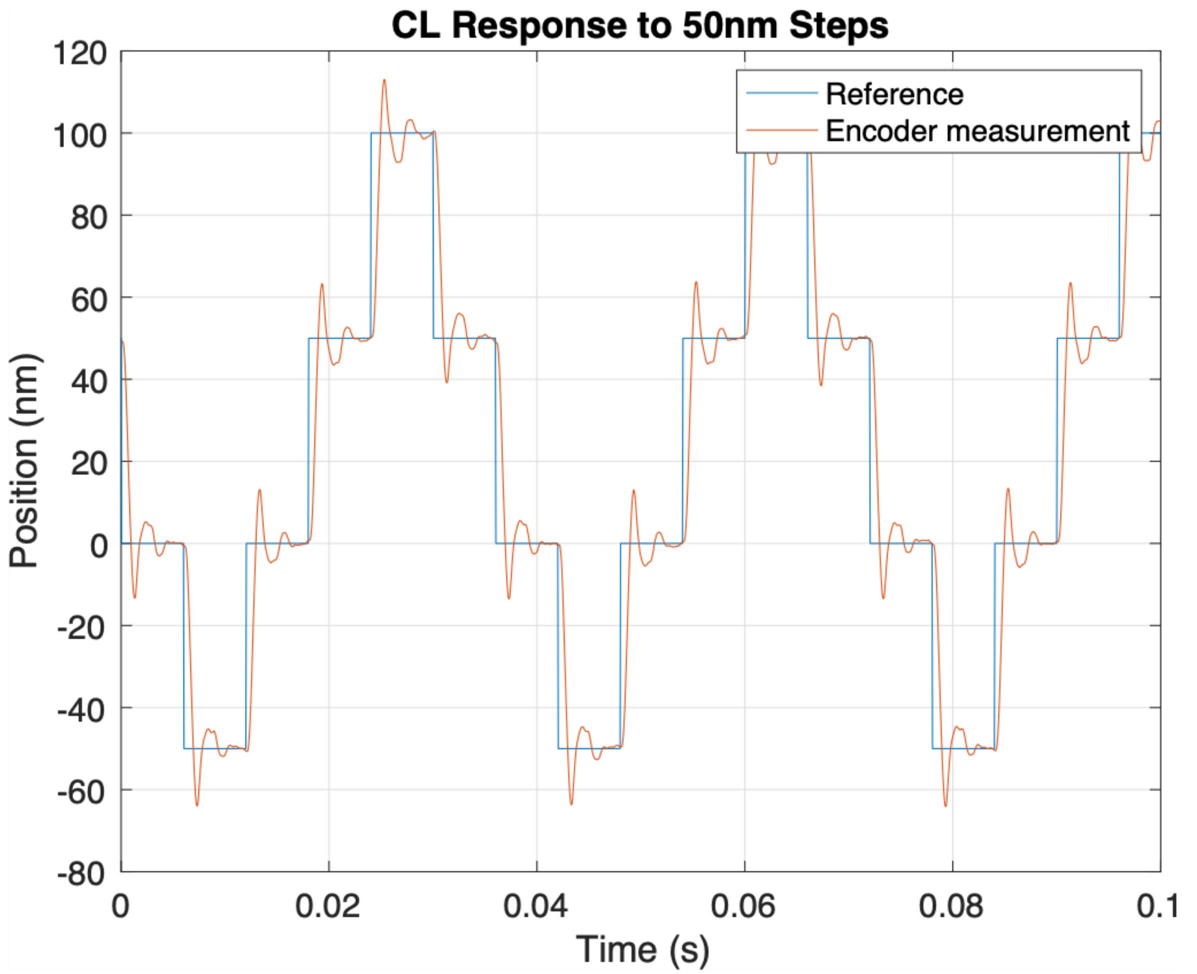
- Feedback with accelerometer measurement is used to dampen resonance near 650 Hz
- Desirable to dampen higher frequency resonances, too, but this is not implemented at this point
- Feedback with encoder measurement is used for position command tracking



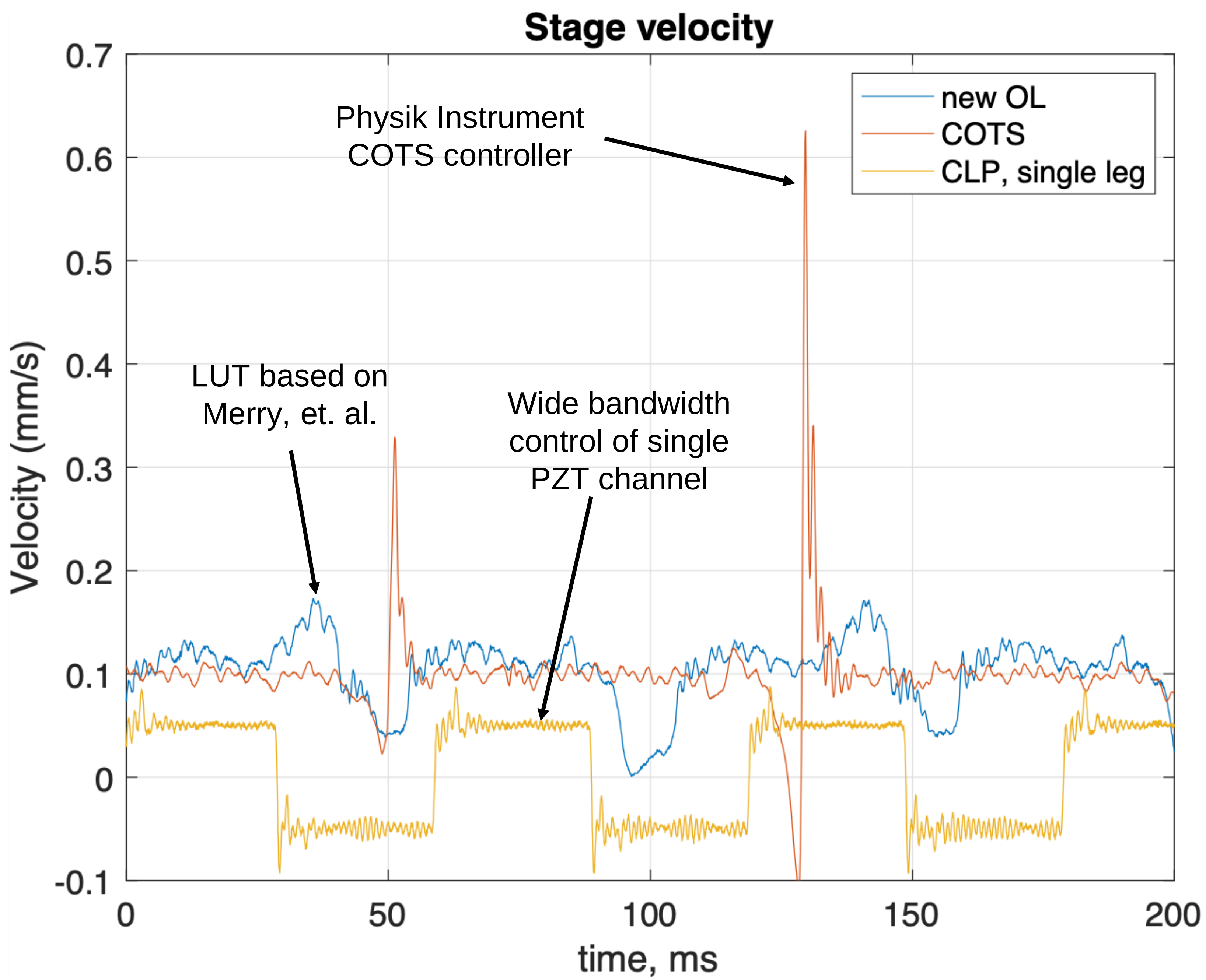
Observations:

- Settling time is close to 4 ms —consistent with bandwidth of stage
- May be possible to tailor closed-loop frequency response properties near 700 Hz to reduce overshoot in time domain response
- Need to determine if plant dynamics change as a function of the nominal operating phase of the PZT voltages





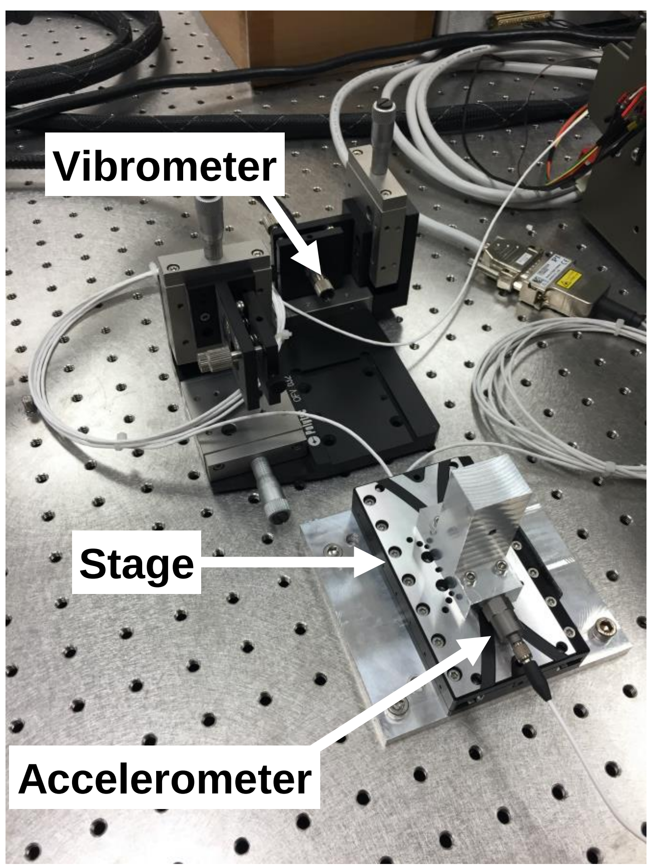
Nanometer motion control project - Apr 23, 2020



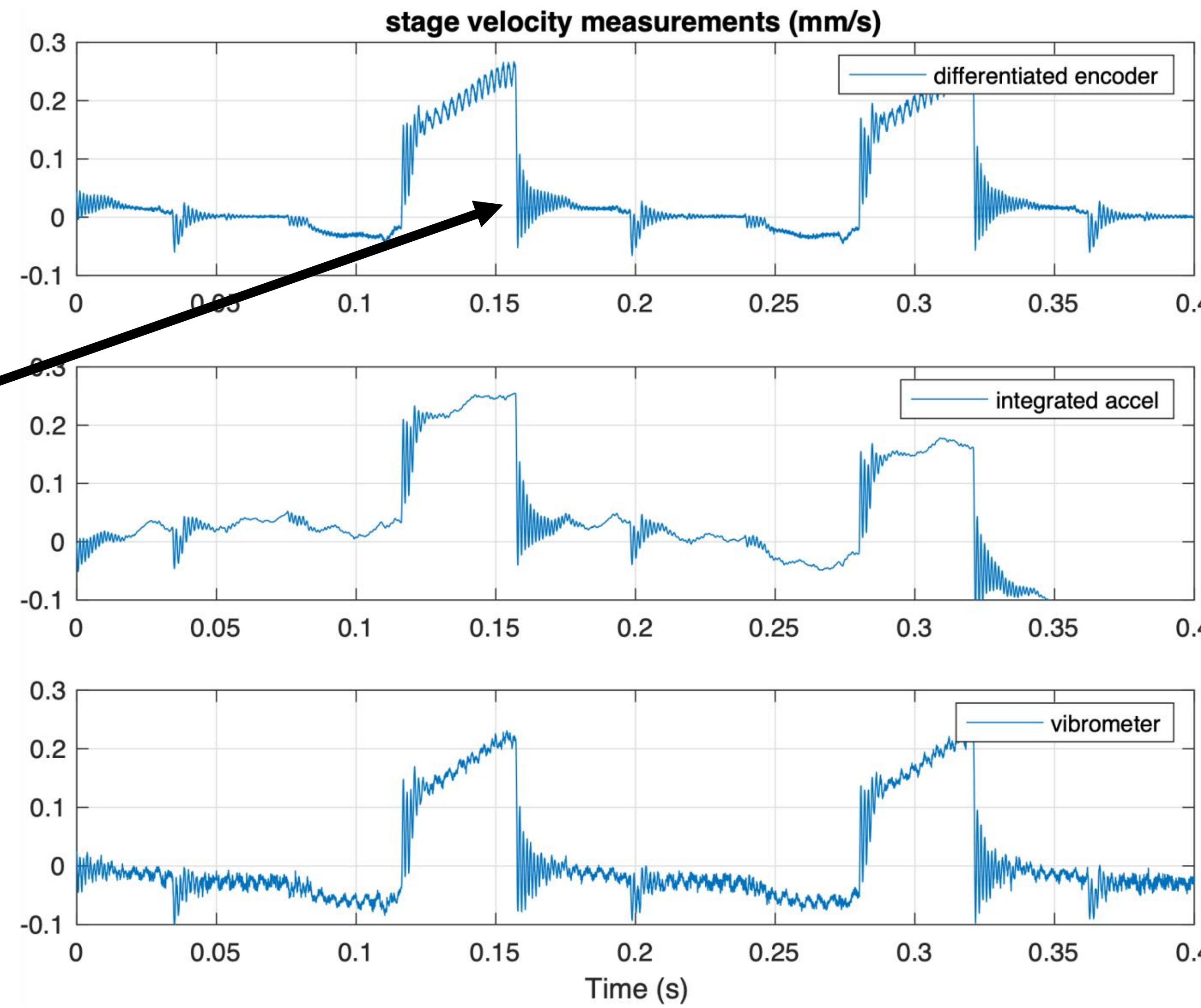
- LUT will continue to be improved to eliminate large dips in stage velocity
- Integrating new LUT with wide bandwidth control based on accelerometer and encoder feedback will eliminate small amplitude, higher frequency velocity noise

Recent results

- **Stage velocity without accelerometer feedback**

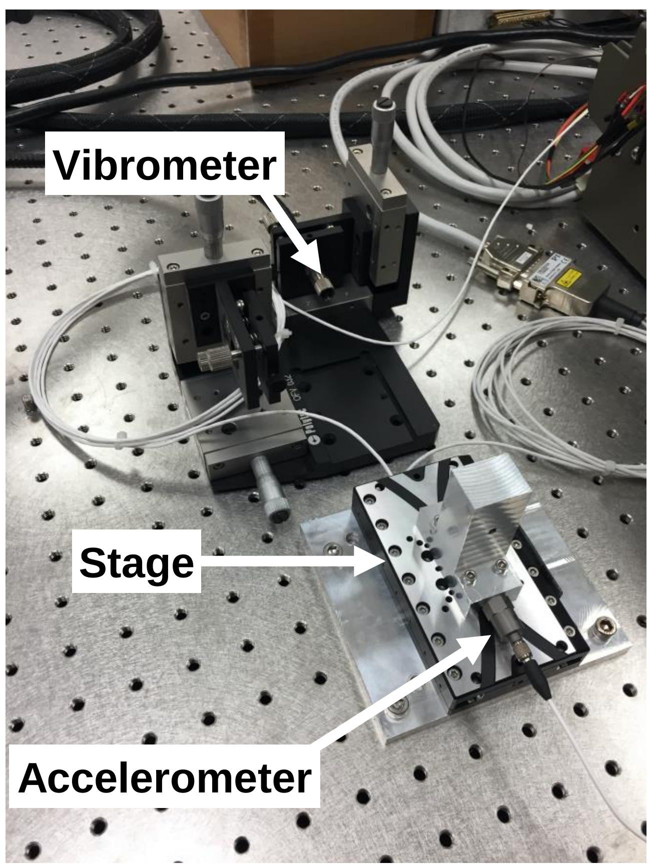


Lightly damped stage resonance

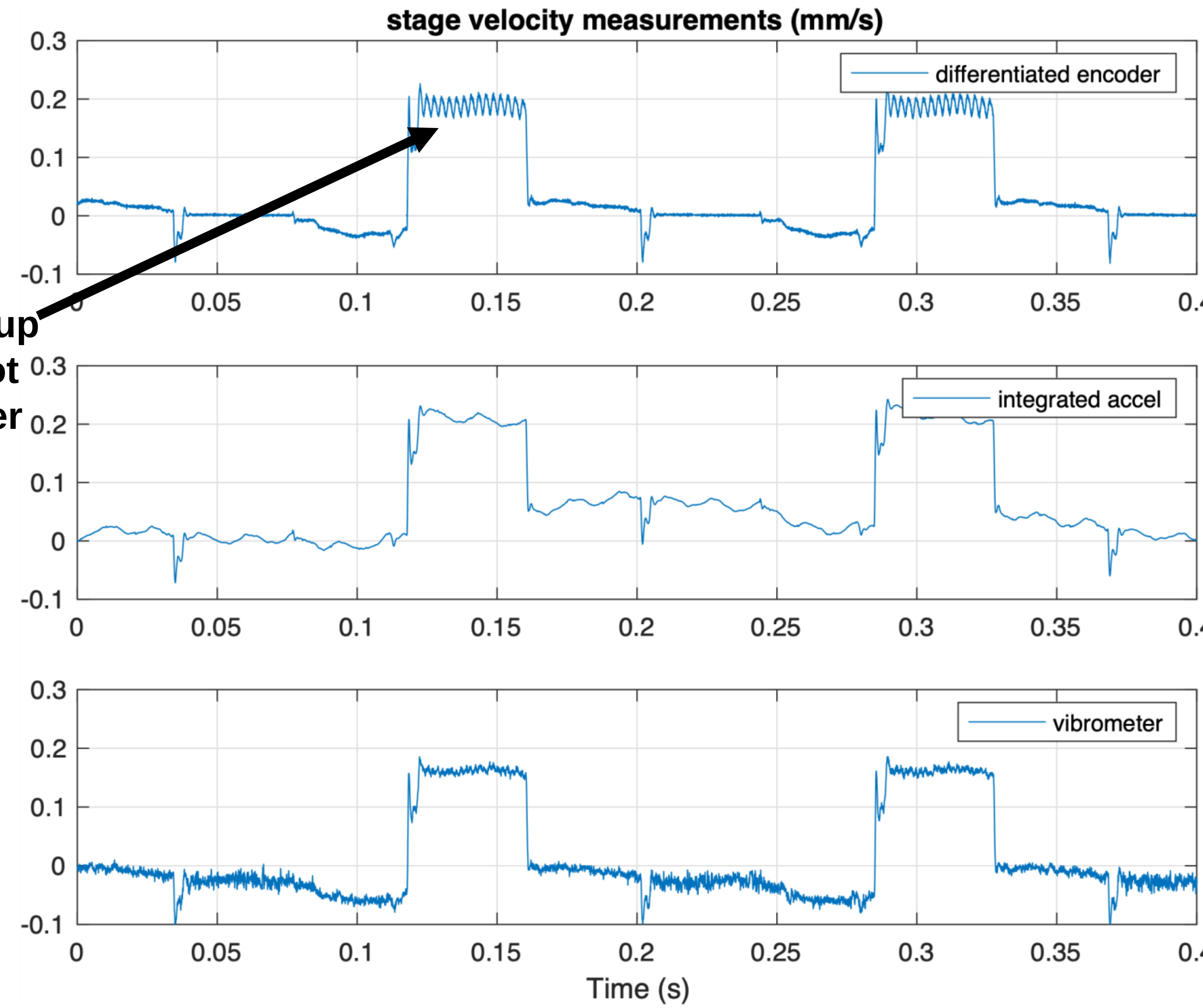


Recent results

- Deviations in velocity occur when both PZT channels are simultaneously engaged with the stage
- Use only one channel at a time to separate effects of each channel on stage velocity
- Accelerometer feedback is used to dampen stage resonance

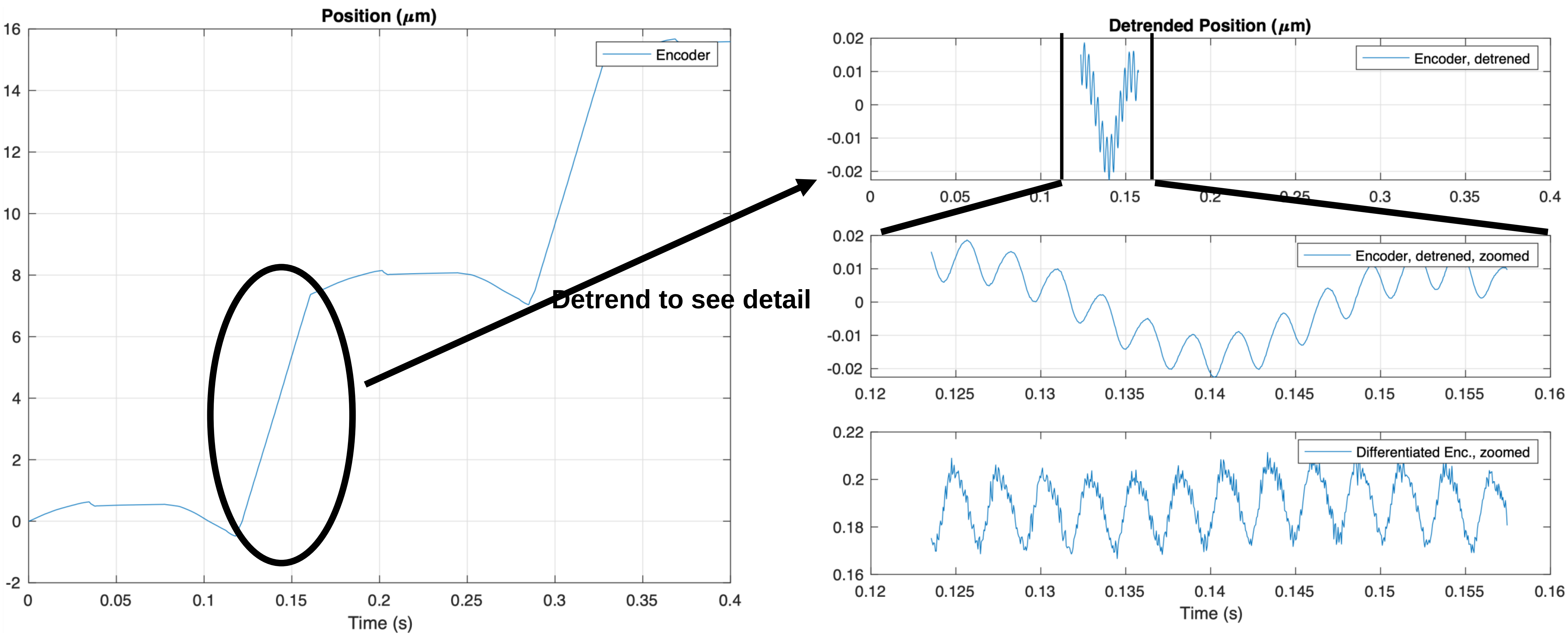


Oscillation picked up by encoder but not accel or vibrometer



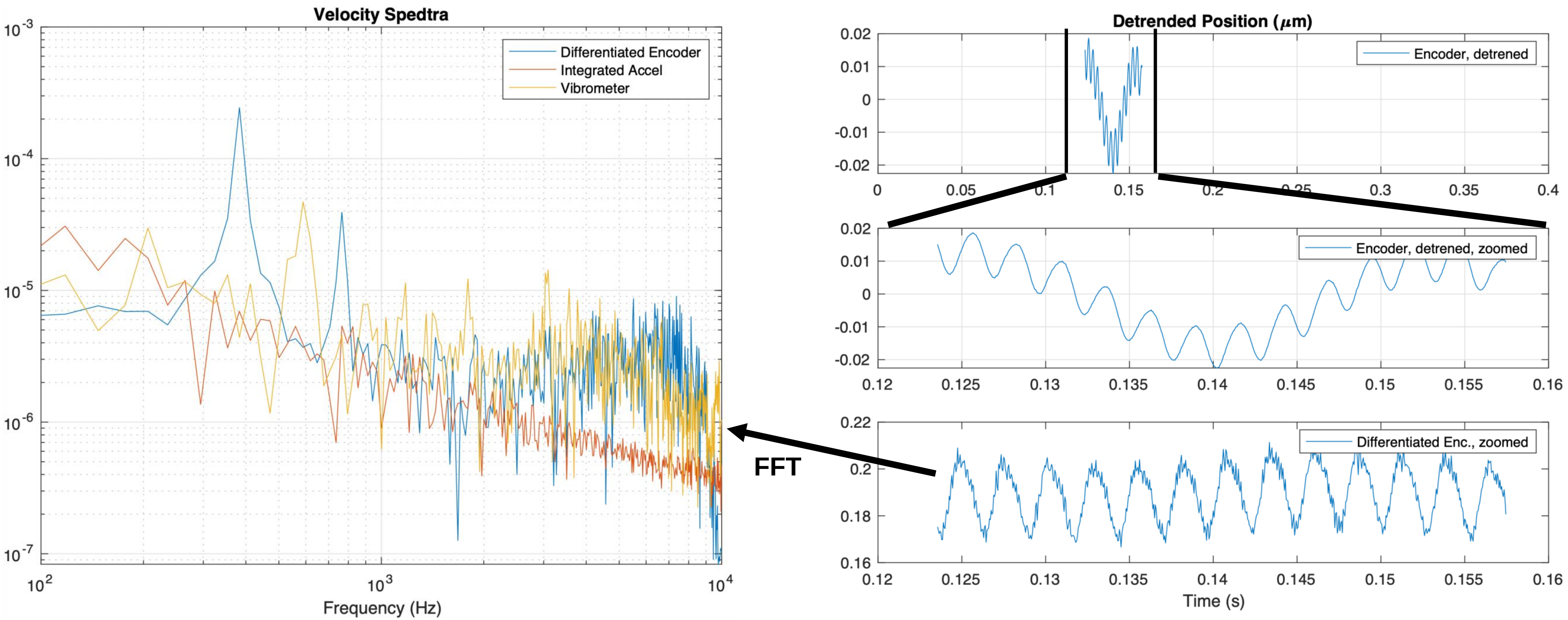
Recent results, cont'd

- **Stage position as measured by encoder**



Recent results, cont'd

- **Stage position velocity spectrum in narrow window**



COTS waveform summary:

- **exhibit large transients in velocity**
- **Low bandwidth feedback on encoder measurement achieves correct mean value of desired velocity**

Modified open-loop voltage profiles:

- **Taken from Merry, et. al.**
- **Only generates basic voltage profiles (no feedback)**
- **Eliminates large velocity transients at the expense of an uneven stage velocity**
- **Cannot avoid "dips" in velocity**

New open-loop profiles:

- **Essentially uses only single PZT in the PZT pair to control the stage velocity**
- **Stage velocity is On-Off**
- **Concerns:**
  - **with only one PZT engaged, stage resonance is more pronounced**
  - **Stage resonances is reduced using accelerometer feedback**
  - **Wideband encoder feedback can be used**
  - **Need to increase "duty cycle" to make approach viable**
  - **Noted jitter in stage velocity during "On" phase (need to determine cause)**