PHASE CORRECTION FOR DYNAMIC MEASUREMENTS

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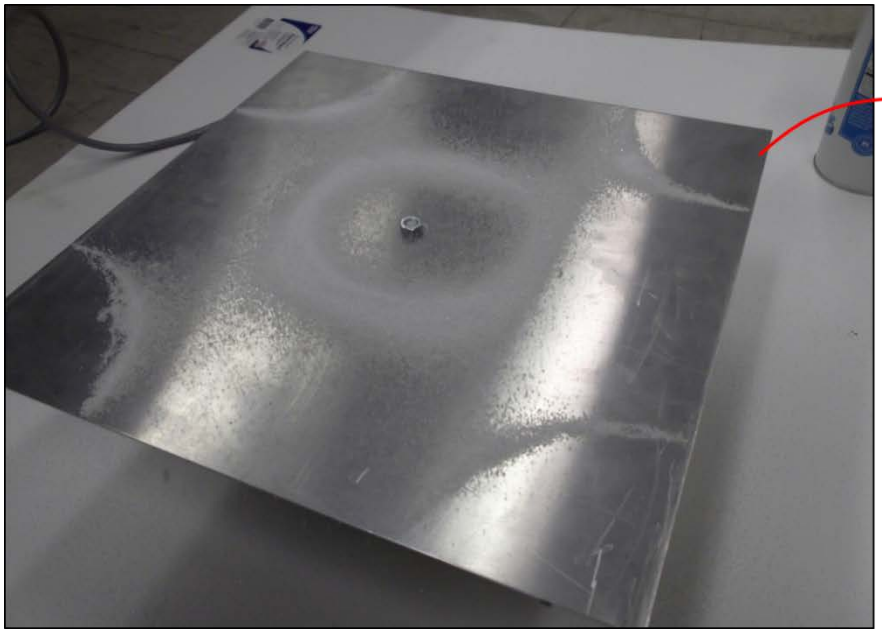
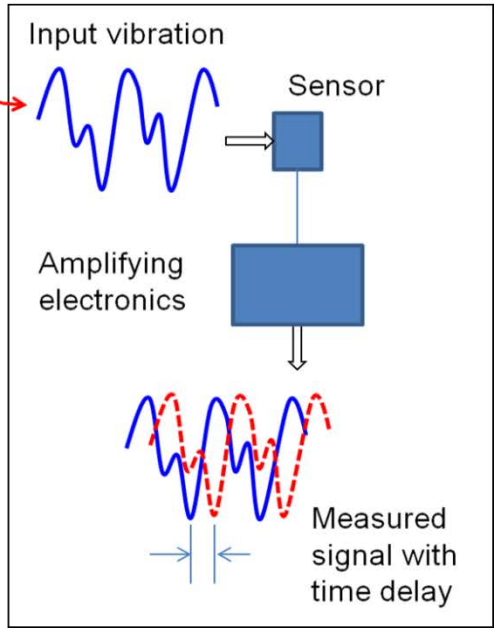
Background

- Monitoring vibrations is an important aspect of industrial processes, such as machining operations, in the aerospace, automotive, and medical fields
- Measurements allow for early detection of developing problems
  - Loose connections, resonance, repeating input forces
- Transducers measure displacements, changes in velocity, or acceleration
  - Calibrated statically but applied for dynamic measurements

Problem





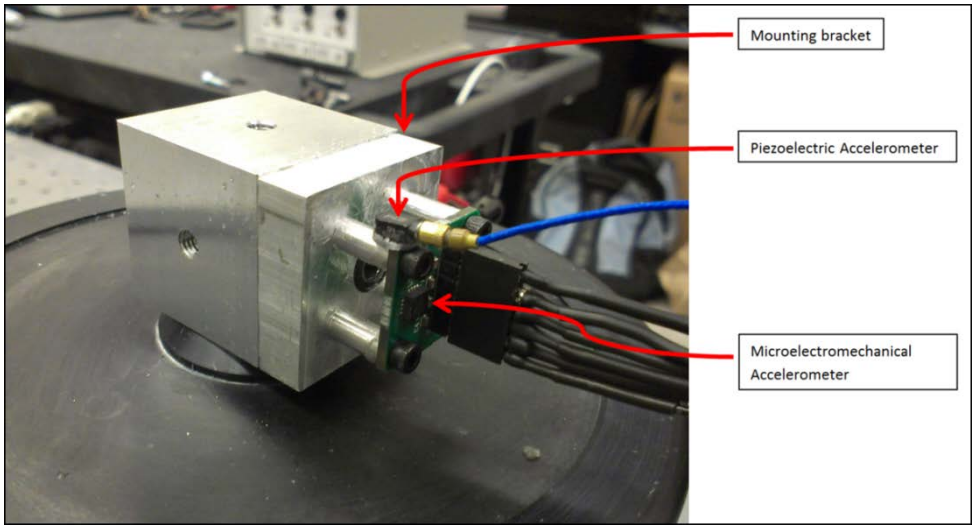
- The vibrations from a resonating surface, such as the plate, may be measured with a sensor whose amplifying electronics could introduce a time delay between the incident motion and sensor signal
- Results in an inaccurate frequency response function for the dynamic measurement

Purpose

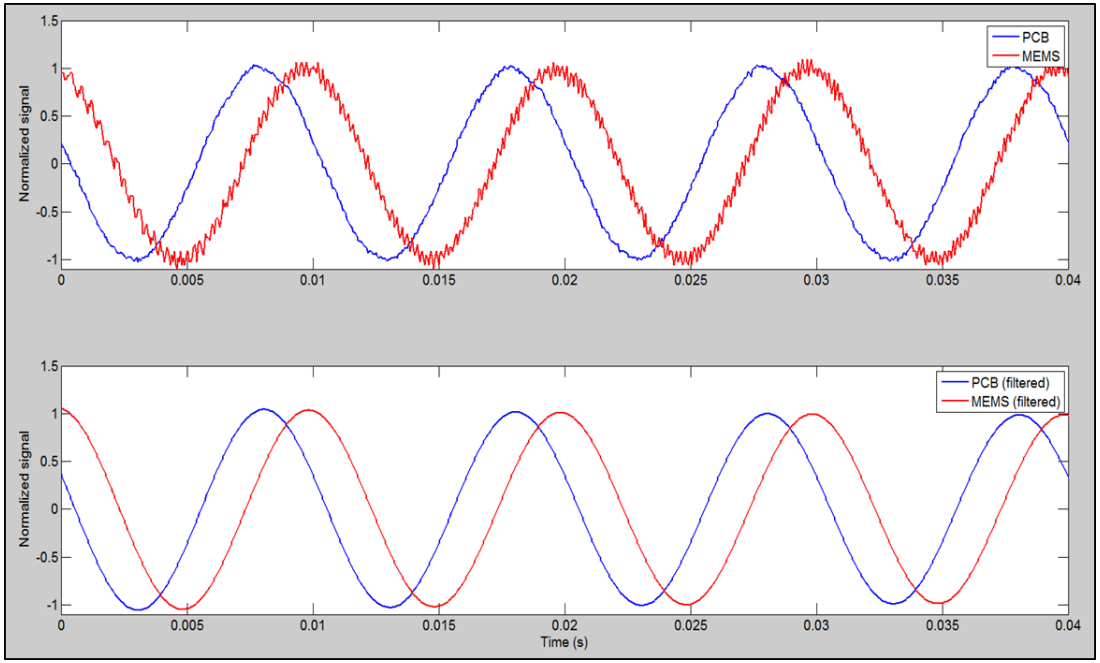
- characterize the frequency dependency of the phase shift associated with microelectromechanical (MEMS) accelerometers applied to vibration monitoring.

Methodology

- Used a piezoelectric accelerometer for reference measurements
  - Industry leading vibration measurement transducer
- Sensors mounted onto modal shaker to provide sinusoidal displacement
- The phase lag can be evaluated by determining the phase shift between two sinusoidal signals.



Initial Results



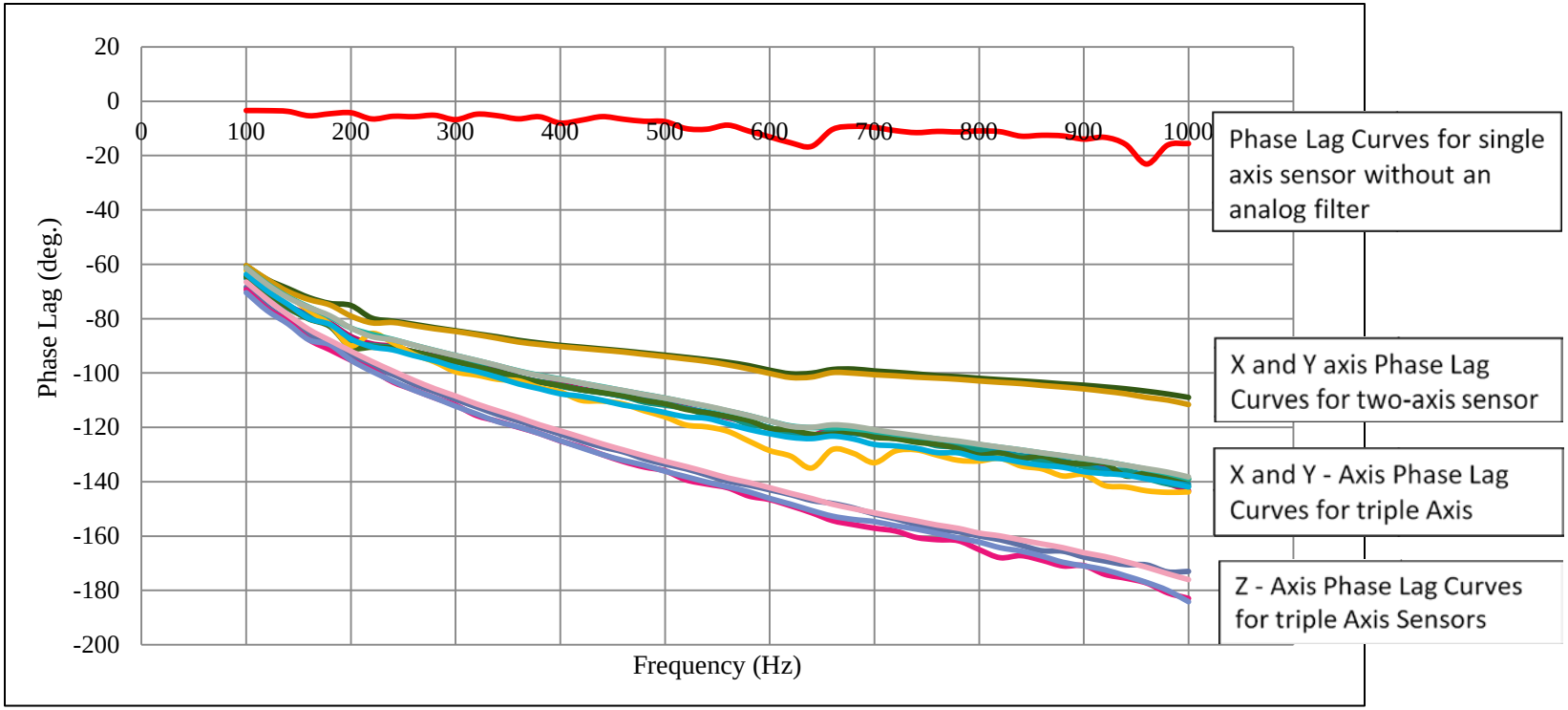
Normalized output at 100Hz

- Third order Butterworth filter used to smooth output signals
- Phase lag ($\emptyset$) at a frequency (ω) was evaluated using the equation

$$\Delta\emptyset(\omega) = \cos^{-1}\left(\frac{x \cdot y}{|x||y|}\right)$$

- where x and y denote the two sinusoidal signals

Results



- Results were consistent with the expected outcome of higher phase lag at higher vibration frequencies.
- Use of analog filters causes the phase lag to increase in a non-linear fashion with larger phase shifts
- linearly increasing trend observed from a sensor without an analog filter.
- Coinciding curves were averaged to produce a representative curve for each group

Phase Correction

- Phase correction requires minimizing the phase shift between the MEMS and PCB accelerometer outputs.
- Fitting a trend line to the curve of phase lag allows for a representation of the expected phase trend.
  - the phase lag was corrected by subtracting the products of the fit equation from the values of phase lag measured at each frequency.
    - - Linear Corrected Phase Lag

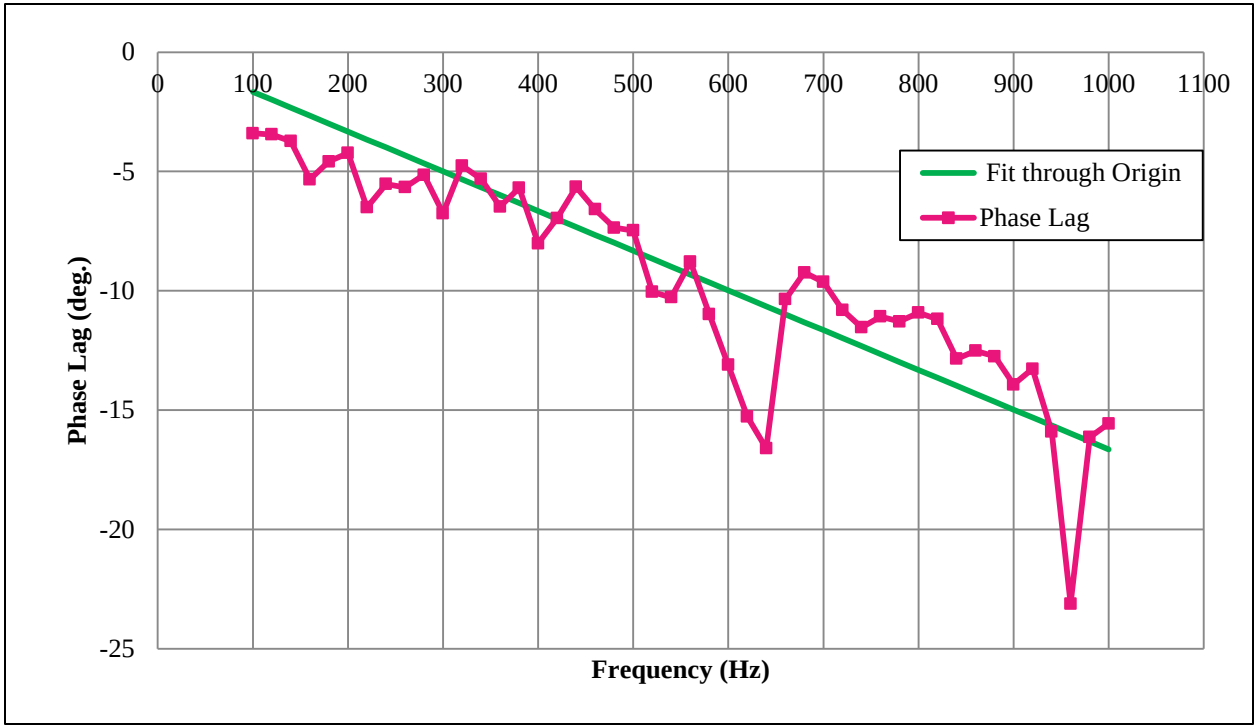
slope

$$\emptyset(\omega)_{cor} = \emptyset(\omega)_{meas} - \Delta\theta * \omega$$

    - - Non-Linear Corrected Phase Lag

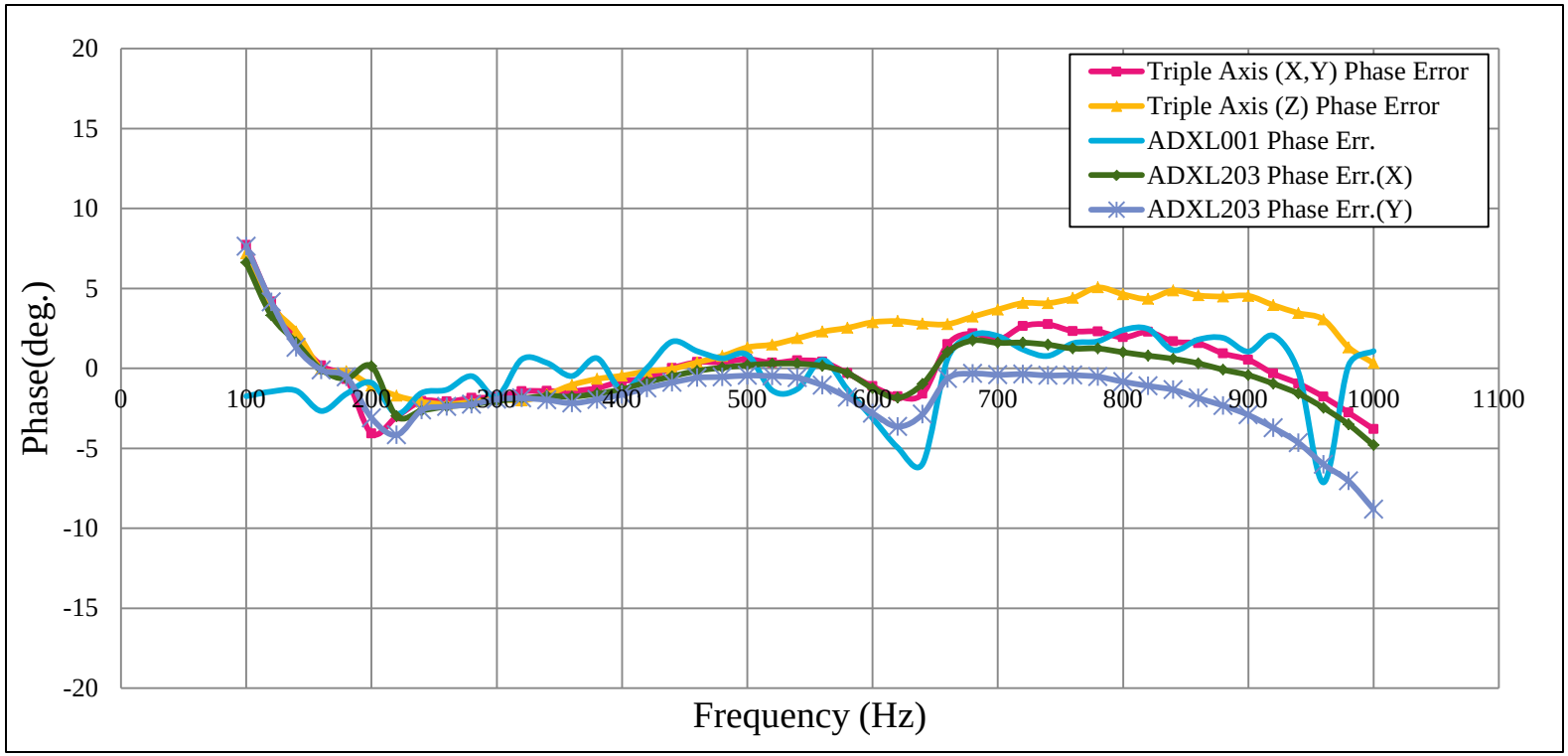
$$\emptyset(\omega)_{cor} = \emptyset(\omega)_{meas} - (C1 * \omega^2 + C2 * \omega + C3)$$

Curve Fitting



- Due to the fact that there is no phase lag at zero frequency, a linear regression fit through the origin was evaluated for the linear, non-filtered curve. (shown above)
- Non-linear curves (for the analog filtered MEMS accelerometers) used a polynomial fit.

Corrected Phase



- Subtracting the fit equation products from the measured produces the above curves representative of corrected phase for the indicated sensor axes.
- The noise in the above chart is due to resonance in the mountings of the accelerometers

Conclusion

- Correction of the phase lag enables dynamic measurements from the MEMS sensor with increased accuracy.
- This method is also adaptable to other transducers and may allow low cost MEMS sensors to be more widely implemented in precision applications.