Magnetic Phase Shift Torque Sensor

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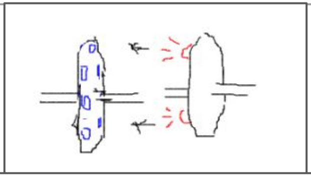
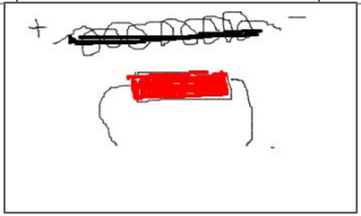
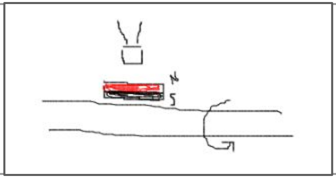
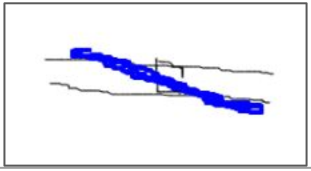
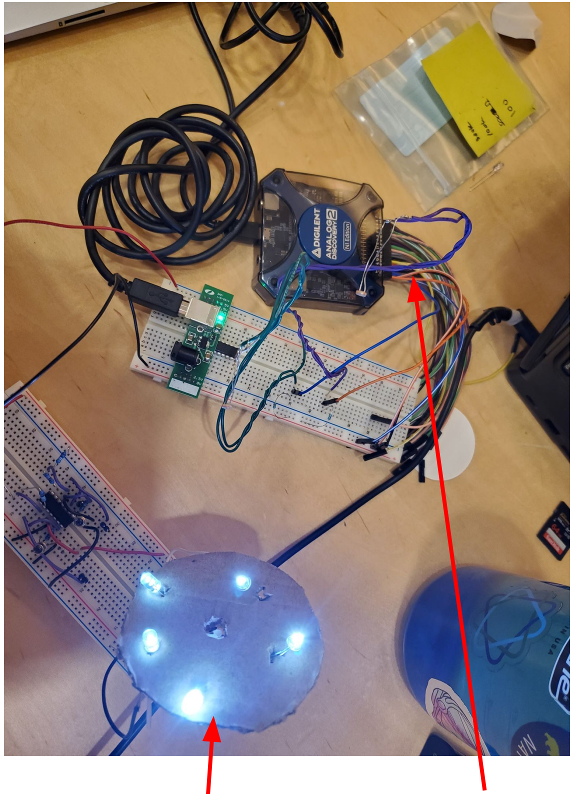
Ideation

Idea	Explanation	Sketch
Optical	Rotating disks, one with LEDs, one with photodiodes	
Inductor (eddy current solenoid)	Run current through inductor on axle, measure current on inductor parallel	
Permanent Magnet	Dipole magnet attached to axle, sense when North	
Strain Gauge	Attach parallel to axle, look at degree of twist	

Feasibility Testing - Optical

- Placed cardboard piece over rotating shaft of impact driver and applied varied torque
- Detected changes in photoresistor value based on displacement of light when shaft deformed
- Needed multiple photodiodes and lights to quantify extent of deformation

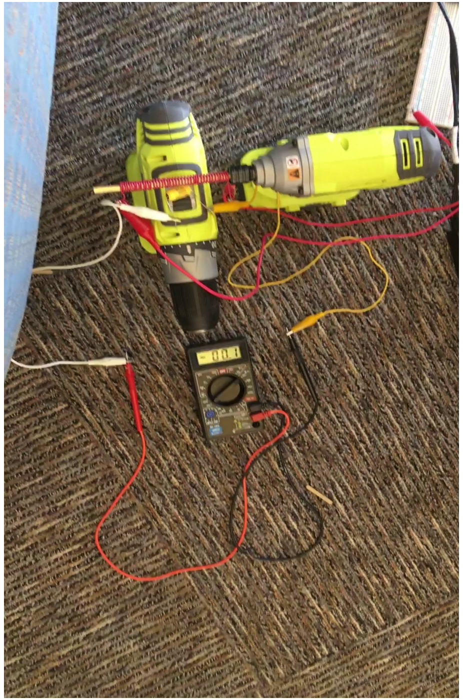
Conclusion: Implementation would require extensive geometry of components and heavy software component



Feasibility Testing - Eddy Currents

- Attempted to measure the eddy currents induced by a rotating shaft
- Used a drill to rotate a shaft, and an inductor to measure the eddy current

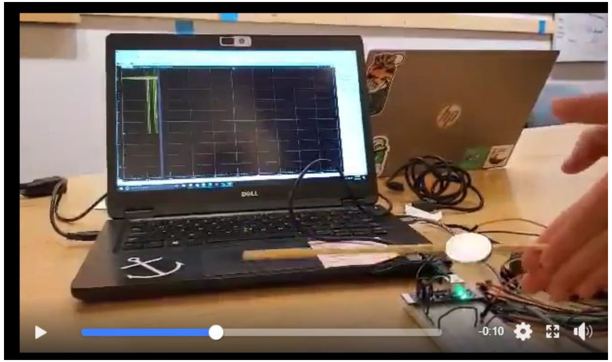
Conclusion: Implementation probably possible, but we don’t know how. The method of using eddy currents requires a more fundamental understanding of electrostatics than we have.



Feasibility Testing - Hall Effect

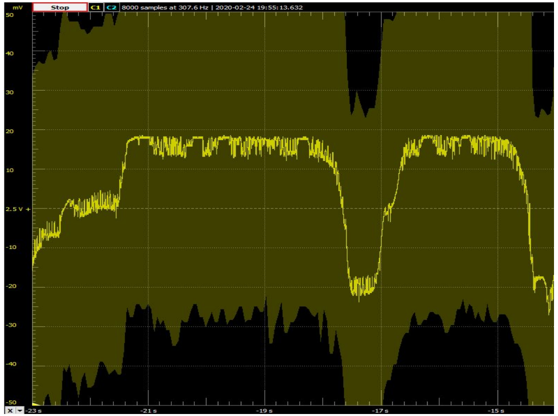
Permanent Magnet:

- Rotated magnet over a hall effect sensor (using a dowel)
- Detected changes in sensor output



Inductor:

- Measure response to varying distance from inductor and varying current

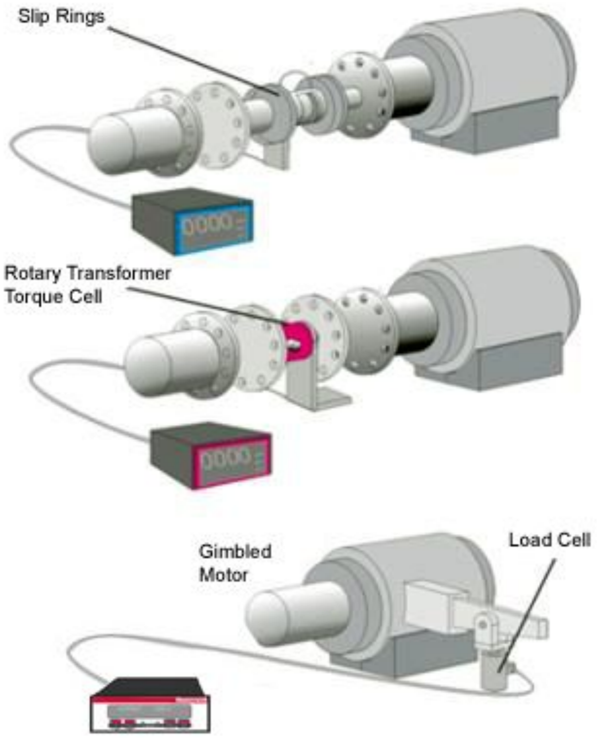


Conclusion: Phase shift is visible, method is viable.

Feasibility Testing - Strain Gauge

- Performed theoretical analysis, as components were prohibitively expensive
- Required components were two strain gauges to measure torsional load, however combination of small size and accuracy were hard to balance

Conclusion: Implementation was straightforward, but iteration would come at a heavy cost.



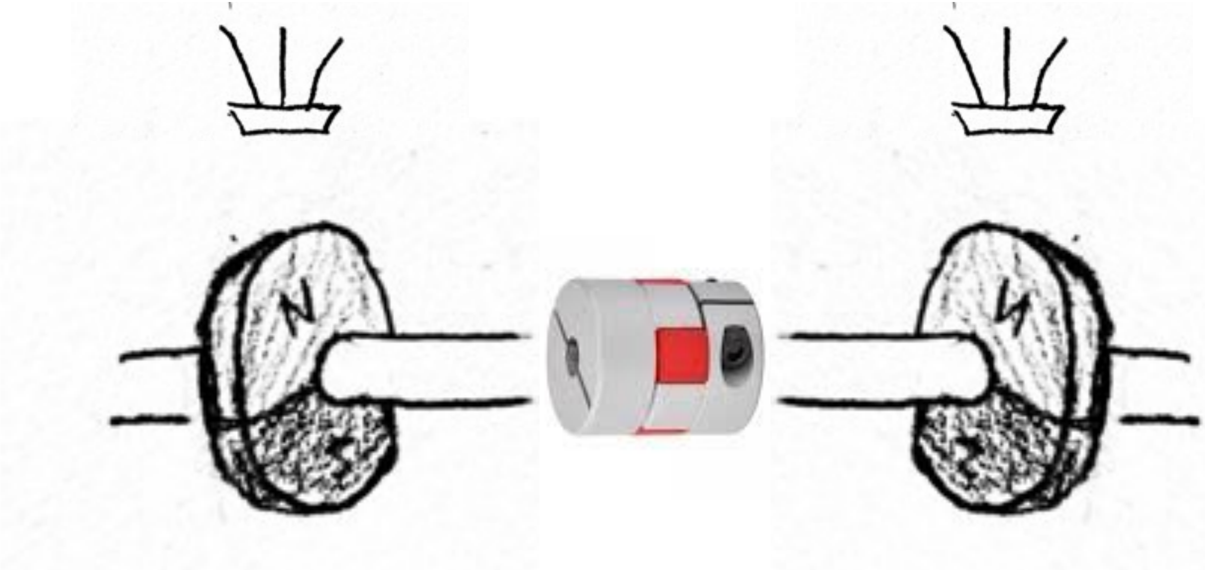
Final Decision

We selected to move forward with the **Hall effect sensor-based design** because it has:

- High opportunity for iterative development
- Challenges aligned with our learning goals
- Clearest path to direct torque measurement
- Low complexity in terms of collecting raw data
- Dependable and predictable results
- Scalable, depending on products available for purchase

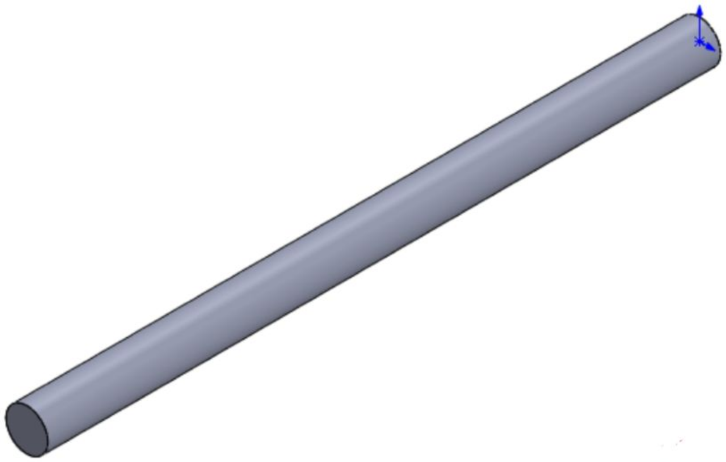
High level overview

- Prove that the behavior of magnets can achieve a torque measurement of adequate granularity, for both static and dynamic applications
- Main concepts to harness for success:
    - Magnets
    - Hall effect sensors
    - Axles
    - Couplers



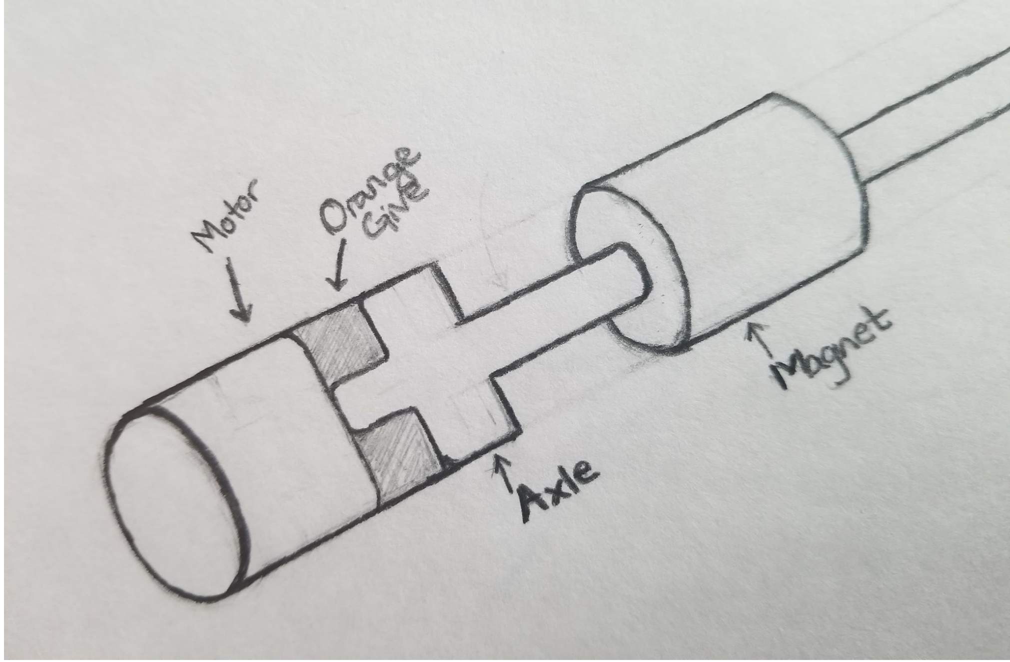
Axle Testing

- Phase shift measurement requires flexible shaft
- Experimented with different materials and densities
    - TPU - 30% fill
    - TPU - 70% fill
    - PLA - 50% fill
    - PLA - 70% fill



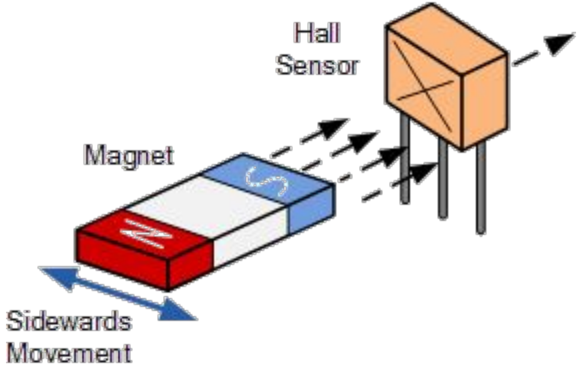
Couplers

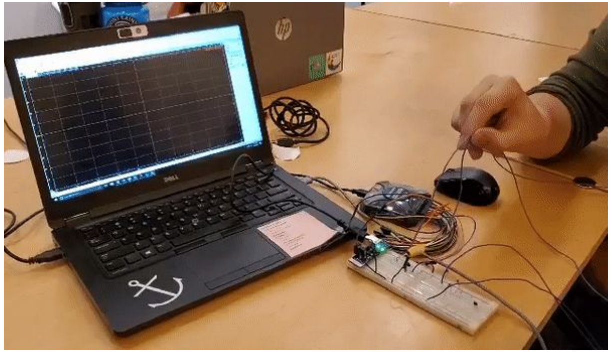
- Wanted to maintain couplers present in default motor configuration
- Ideas to 3D print axles with coupling ends
  - Magnet within
  - Magnet on the outside
- Two magnets mounted on either end of axle and couplers



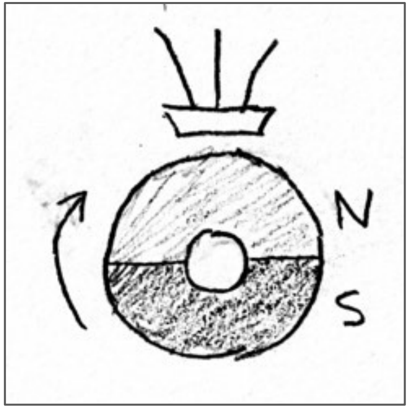
Hall Effect Sensors

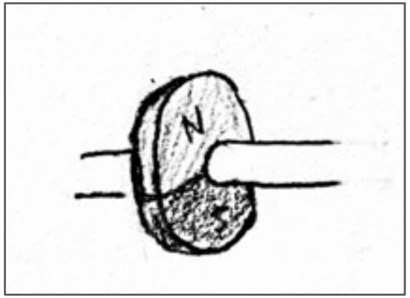
- Movement of charge based on applied magnetic force
- 3 pronged hall effect, coupled with amplifier
- Head on and side to side detection (not all or nothing)
- Required a diametric form of magnet to take full advantage of hall effect sensing

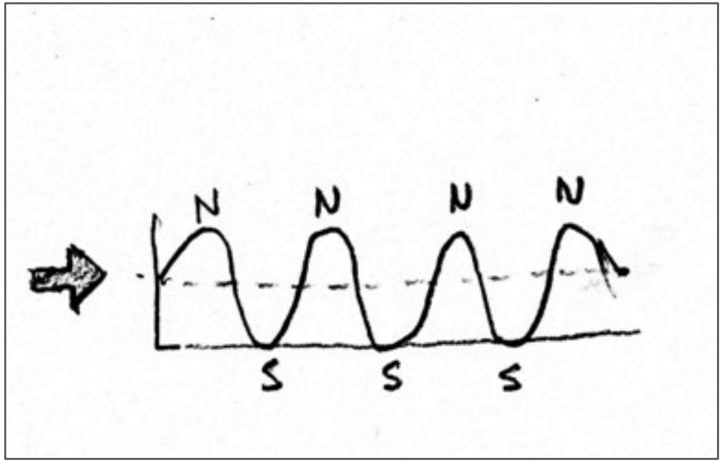




Diametric magnets



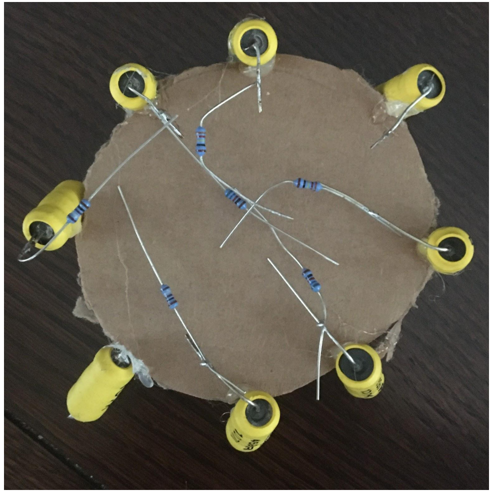


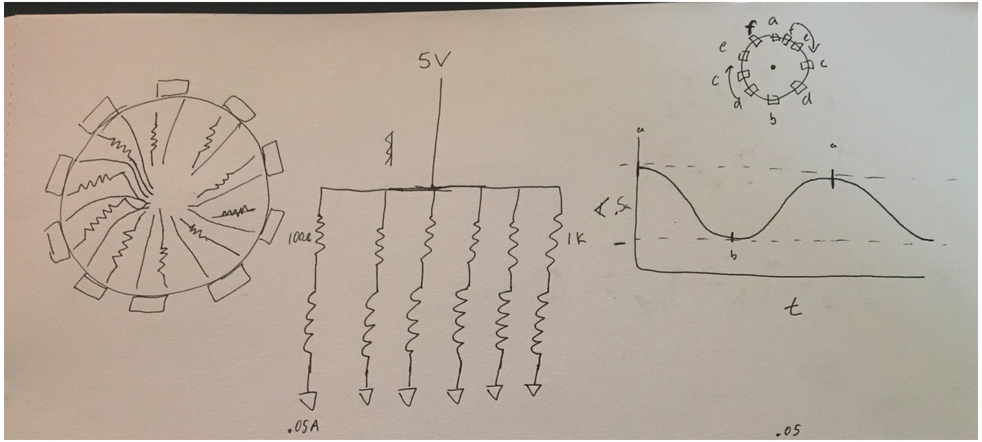


Electromagnetic Ring

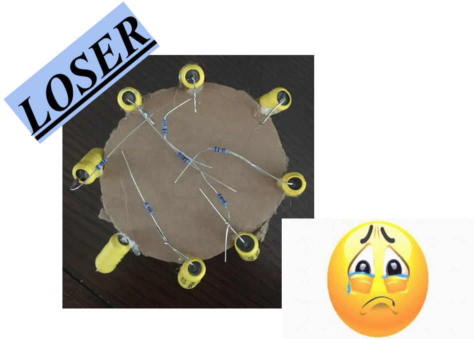
We played with the idea of creating an electromagnetic ring that would have a diametric field.

- Used parallel LR circuits to create desired mag. field
- Chose resistor values so that the strength of the fields followed a sinusoidal pattern.





Permanent vs Electro Magnets



BENEFITS	DOWNFALLS
Complete control of design	More parts
Fun, got to make something weird	10-fold more complexity
Parts were cheaper	Electronics on shaft

BENEFITS	DOWNFALLS
Didn’t have to make	Can’t adjust
Knew exactly how it behaved	Was a design restriction
Sturdy	

Software - Phase Offset Determination

Use difference between magnet outputs to determine phase shift due to torque using hardware like phase comparator IC or software-based methods such as autocorrelation.

```
# Determine the phase offset between the two signals using the correlation.
correlation = np.correlate(ref_signal, shifted_signal, 'full')
time_delta = np.linspace(-time[-1], time[-1], (2*number_of_samples)-1)
time_shift = time_delta[correlation.argmax()]
# Constrain to between pi and pi.
calc_phase_shift = ((2* np.pi) * (time_shift/(1/frequency) % 1))
# Prints the actual value of the shift and the adjusted phase shift.
print("Actual phase shift: %f", phase_shift)
print("Computed phase shift: %f", calc_phase_shift)
```

Firmware - Torque Calculation

- Build calibration curve to quantify directly proportional relationship between the phase shift and torque
- During operation, quantify phase shift and use calibration curve to convert to torque
- Built software mockup in Arduino