Queen's Racing Formula SAE Pneumatic Shifting System

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Requirements/Problem Breakdown

Current Problem:

- Current system solenoid valves are rated lower than the running pressure
- Likely to leak or malfunction due to higher pressures.

Objectives:

- Minimizing shift times
- Optimize reliability of the system

Justifications and Reasoning:

- Mathematically and Model/Simulation
- Common sense

Current System

1. **Pressure vessel**
   - The pressure tank
   - Pressure regulator

2. **Solenoid valves**
   - 3-way & ECU controlled
   - Open to ATM by default
   - Connected to pressure tank with a signal input

3. **Actuator**
   - 2-way actuator
   - Connected to a mount and a lever

Gearbox and Motor

- **KTM 450**
  - Single Cylinder 4-Stroke

- **Dogbox Gearbox**
  - 5 gears plus a neutral
  - Neutral is half a shift above 1
  - The pedal is replaced with the lever-cylinder system
  - Torque required to shift is reduced with spinning gears

Unknowns

Fixed/Independent Unknowns:

- Required torque to shift
  - First to second gear
  - Second to first gear
- Required angle change to shift

Dynamic Variables:

1. Regulator output pressure (P)
   - Affects the shift time
2. Bore of the cylinder (b)
   - Function of force and pressure
3. Lever length (r)
   - Function of output force and torque
   - Affects the stroke length

Assumptions for the Simulation

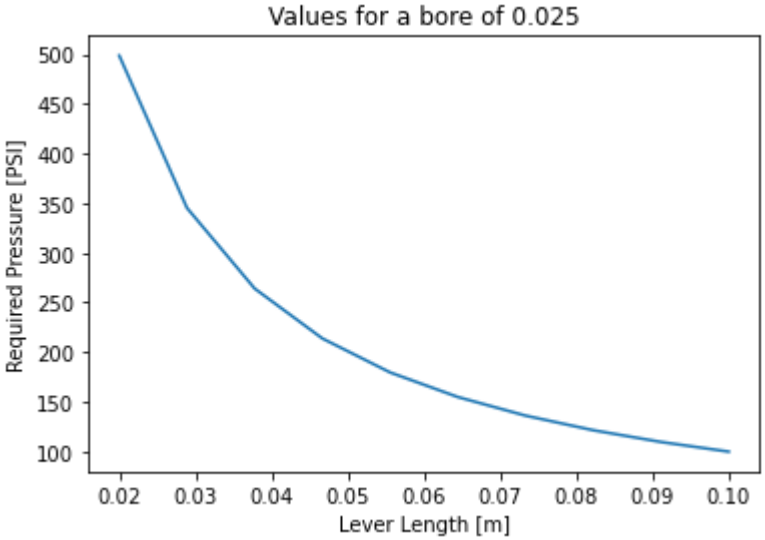
- **Small angle approximation for stroke length**
  - $S \approx r * \sin(\theta)$
- **Pressure is constant**
  - Tank pressure is much higher than regulator pressure
- **Temperature is constant**
  - Temperature drop due to expansion is negligible
- **Force is constant**
  - Air fills the actuator instantly
- **Change in area dependent on the push rod**
  - The area that the pressure can be applied is decreased by the push rod
- **Safety factor of 1.5 applied to torque**
  - To account for the above assumptions

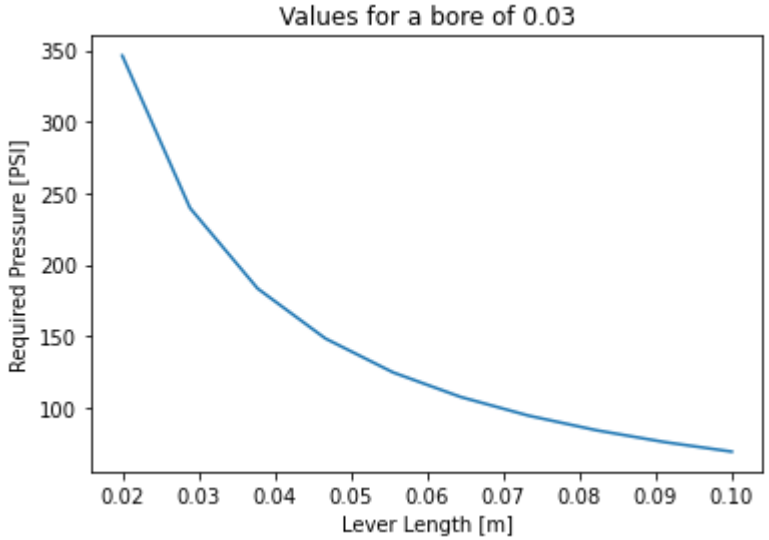
Simulation

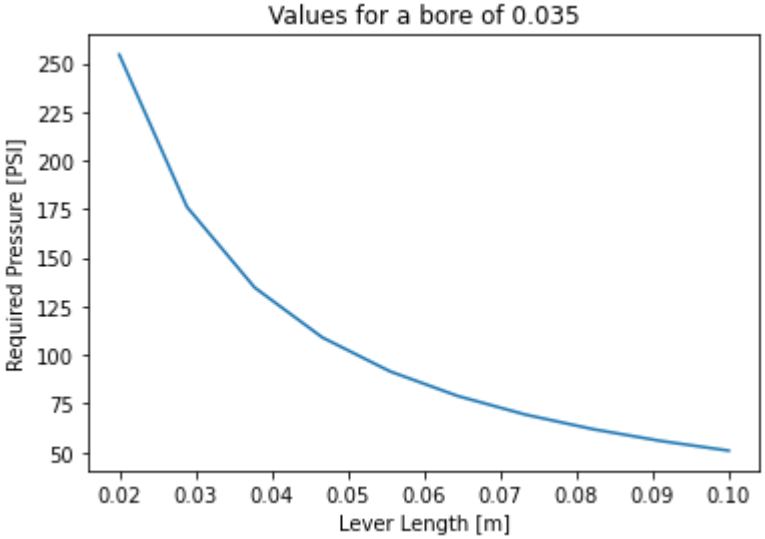
The simulation shows the **pressure vs the required lever length** for a torque of $15\ Nm\ *\ 1.5 = 22.5\ Nm$

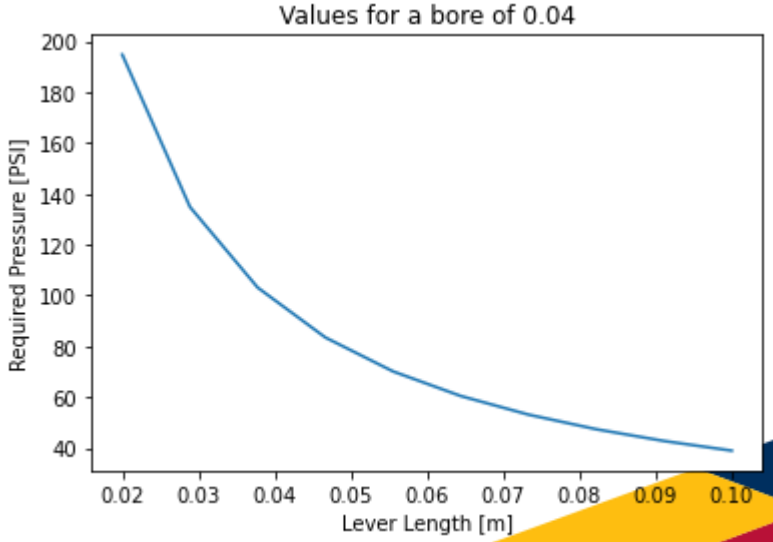
- Bore and pressure are inversely proportional at a fixed force
- Pressure output can be varied at the regulator at any moment

Simulation

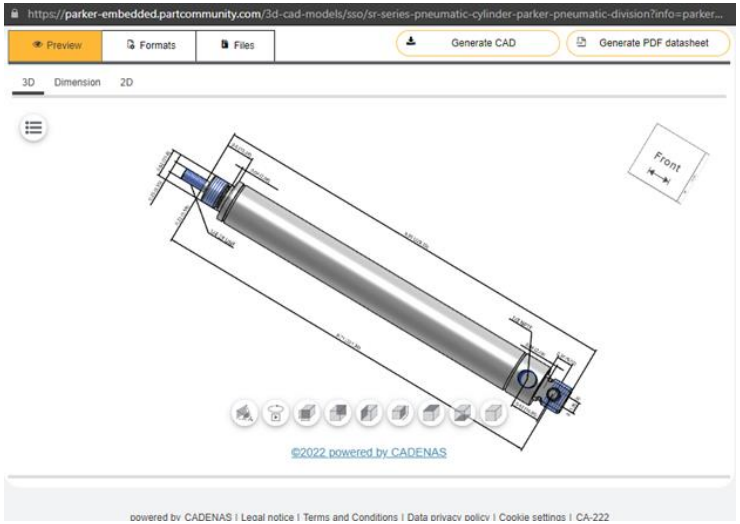

Values for a bore of 0.025
Required Pressure [PSI]
500
450
400
350
300
250
200
150
100
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
Lever Length [m]

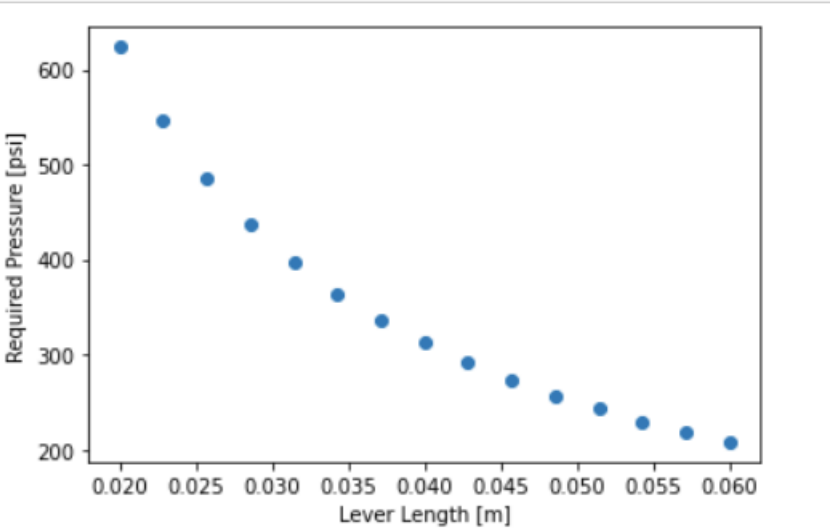

Values for a bore of 0.03
Required Pressure [PSI]
350
300
250
200
150
100
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
Lever Length [m]


Values for a bore of 0.035
Required Pressure [PSI]
250
225
200
175
150
125
100
75
50
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
Lever Length [m]


Values for a bore of 0.04
Required Pressure [PSI]
200
180
160
140
120
100
80
60
40
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
Lever Length [m]

Proposed Actuator 1





Bore: 0.0224 [m]
Stroke Length: 4.0 [in]

Optimized System

Reliable Shifting:

- Low failure chance
  - **Affected by fluctuation in output pressure**
    - Larger bore diameter
    - Longer lever radius means less required force
- Consistent pressure output
  - **Affected by fraction of air released per shift**
    - Smaller volume of cylinder $V = S * \pi \frac{b^2}{4}$
    - Lower pressure output requirement

Optimized System

Fast Shift Times: <200ms

- Distance to shift
  - **Dependant on stroke**
    - Smaller lever arm
- Actuator Velocity
  - **Dependant on force/acceleration**
    - Higher pressure/bore ratio

Next Steps

1. Measure the change in angle and torque required to shift from first to second gear.
2. Use model to determine optimal bore and lever length to required pressure, as well as the resultant stroke length.
3. Choose an actuator based off this data and run model to determine required pressure. Based off required pressure purchase sufficiently rated solenoids.

Further Iteration

1. Use the mass method to find the exact required mass for each shift.
2. Use the mass/shift with number of shifts per lap to find required mass.
   - ~50 per lap from Michigan endurance course.

Any Questions?