NFPA Fluid Power Vehicle Challenge

NFPA Education and Technology Foundation

Midway Review & Update
Cleveland State University
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Our Team

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Introduction

NFPA Fluid Power VEHICLE Challenge

- Engineering Design/Build competition between 11 universities.
- April 10th - 12th in Littleton, Colorado
- Competition categories:
  - Straight sprint
  - Efficiency
  - Regen
  - Endurance

Fundamental Aspects

- Vehicle propulsion must be accomplished through hydraulics with human power serving as the prime mover in the system. A fluid link (oil) is required between the pump and the motor
- The circuit must have the following modes:
  - Direct drive
  - Accumulator charge
  - Regenerative braking
  - Discharging accumulator

NFPA Requirements

- Propulsion must be accomplished through hydraulics with human power serving as the prime mover in the system.
- Must include an energy storage device.
- Two pressure indicators are required.
- Maximum accumulator volume of oil and gas is 1 gallon.
- Maximum vehicle weight without rider is 210 pounds.

Last Year's Design

- Upright design - limited space and reduced stability
- Placed 2nd in the Sprint Race
- Placed 1st in the Efficiency Race
- Placed 3rd overall at the competition

Complications of Previous Design

- High center of gravity
- Limited building space
- Suboptimal valve placement
- 3D-printed oil tank with leaking issues

Improvements for This Year

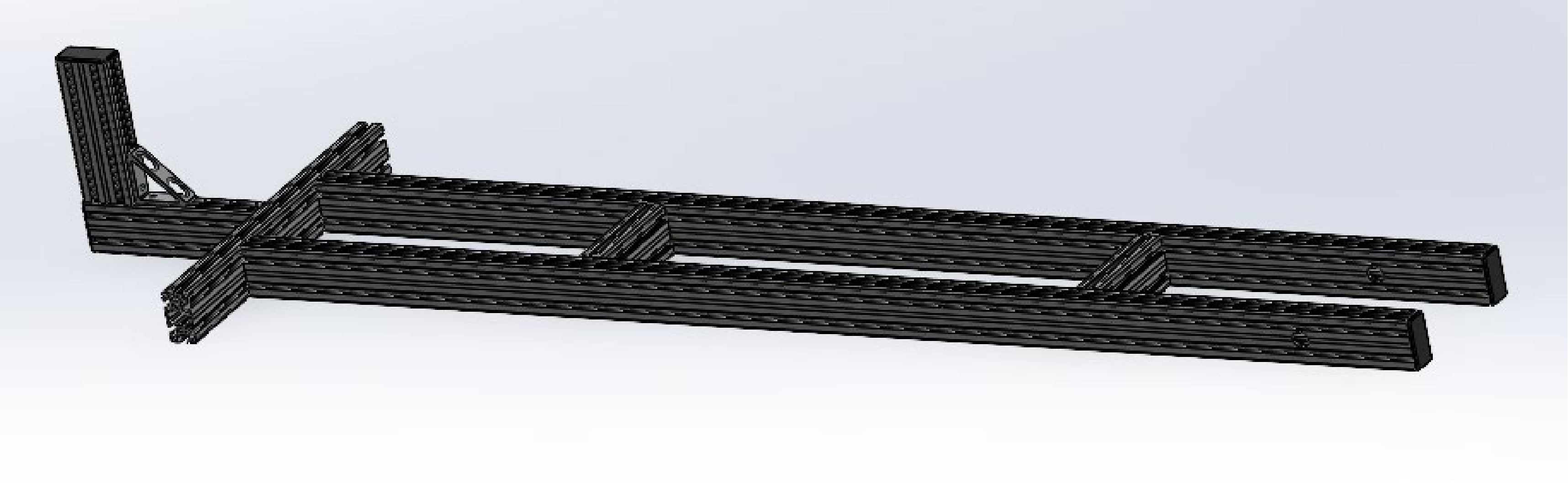
- Moving back to recumbent tricycle
  - Increased space for components
  - Increased stability and safety
- Extruded aluminum frame
  - Modularity
  - Lightweight
  - Increased sturdiness
- Implement solenoids
  - Reduces manual opening and closing of valves
- Streamline hydraulic circuit
  - Adding a manifold to reduce the amount of manual valves

Design Objectives

- Designing a light recumbent style frame
- Redesigned hydraulic circuit
- Experiment with gear selection designs
- Redundancy in safety features

Frame Design

- 40mm x 80mm 6063-T6 Extruded Aluminum
- Frame length: 84.08”
- Frame width: 22”
- Frame weight: 33.70 lbs



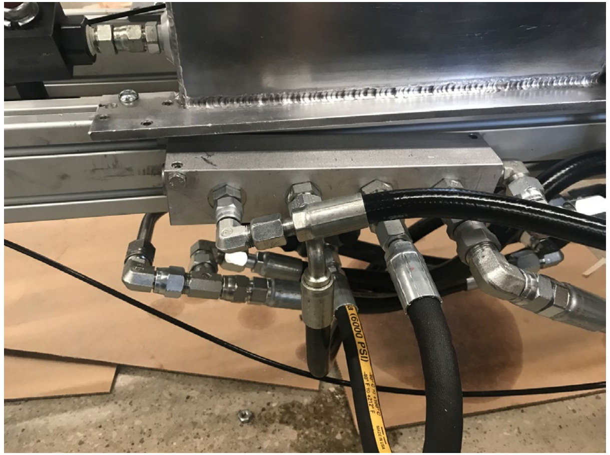
Frame Design

- Recumbent style with rear wheel drive
- Designed in Solidworks
- Extruded Aluminum: Lightweight and modular material
- Required additional reinforcement near the pedals due to high shear stress

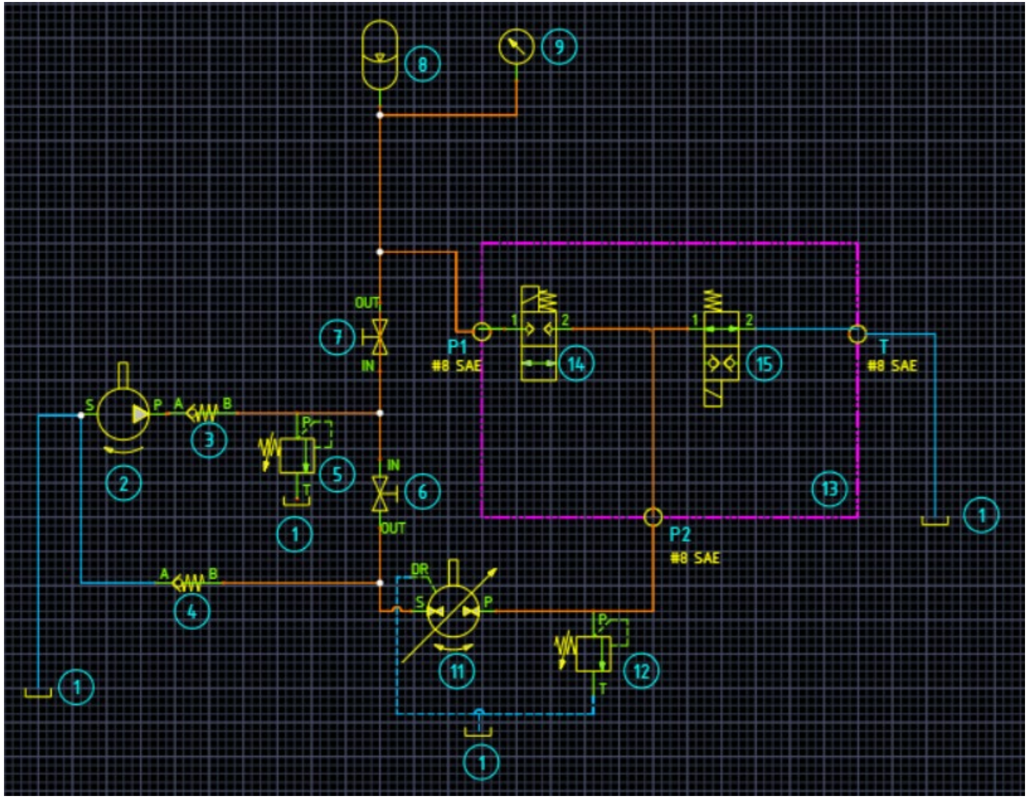
Part Selections

NFPA Fluid Power Vehicle Challenge

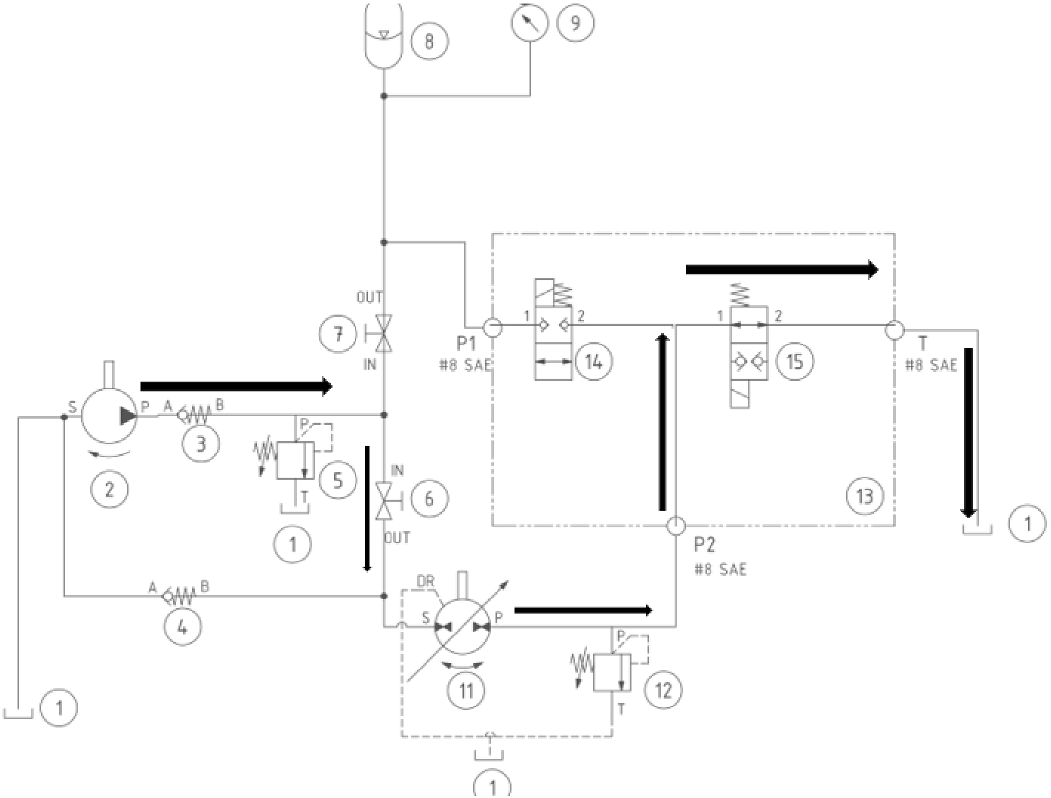
- ½” fitting and tubing - increased flow
- Solenoids - removes 2 manual ball valves
- Manifolds - streamlines plumbing
- Pump .659 CID - highest displacement pump
- Motor 1.025 CID - highest displacement motor
- Gear Ratio: 3:2 for pump



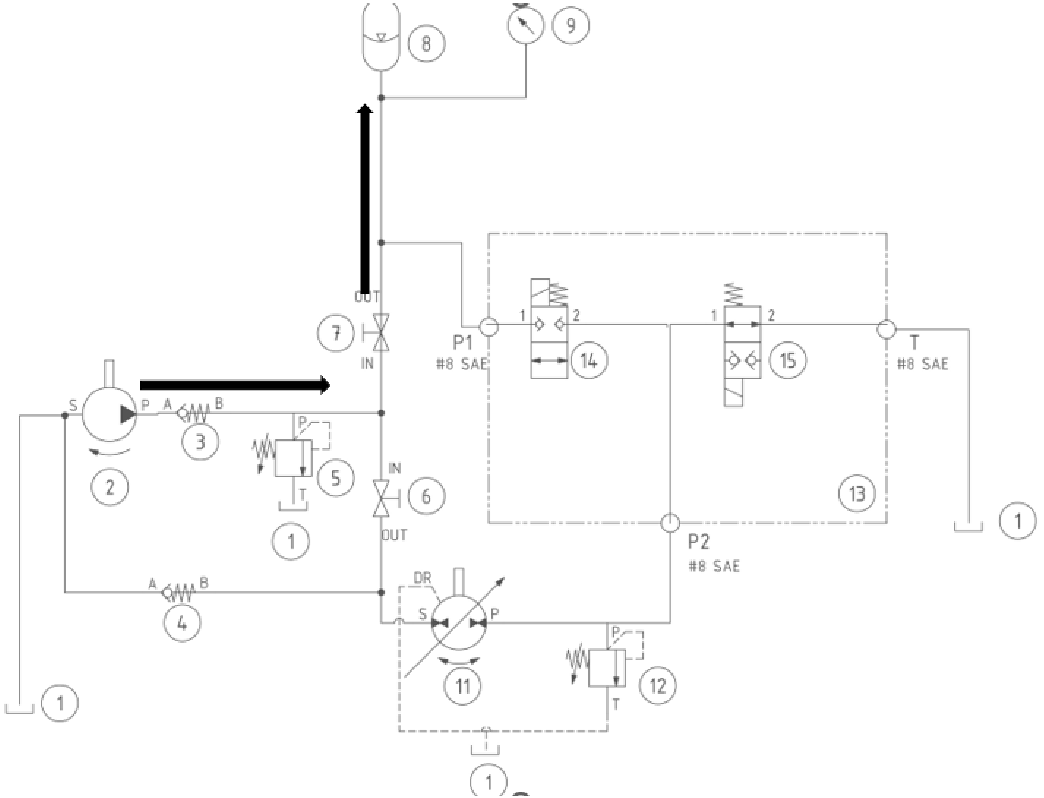
New Hydraulic Circuit Design



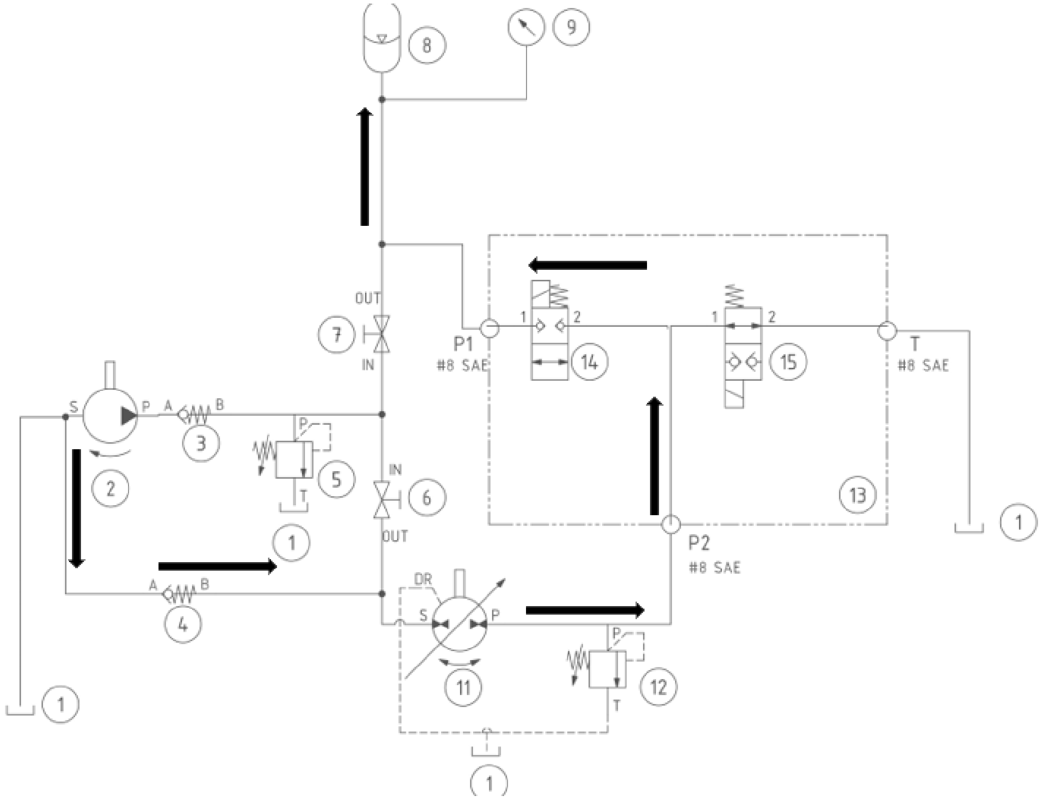
Direct Drive



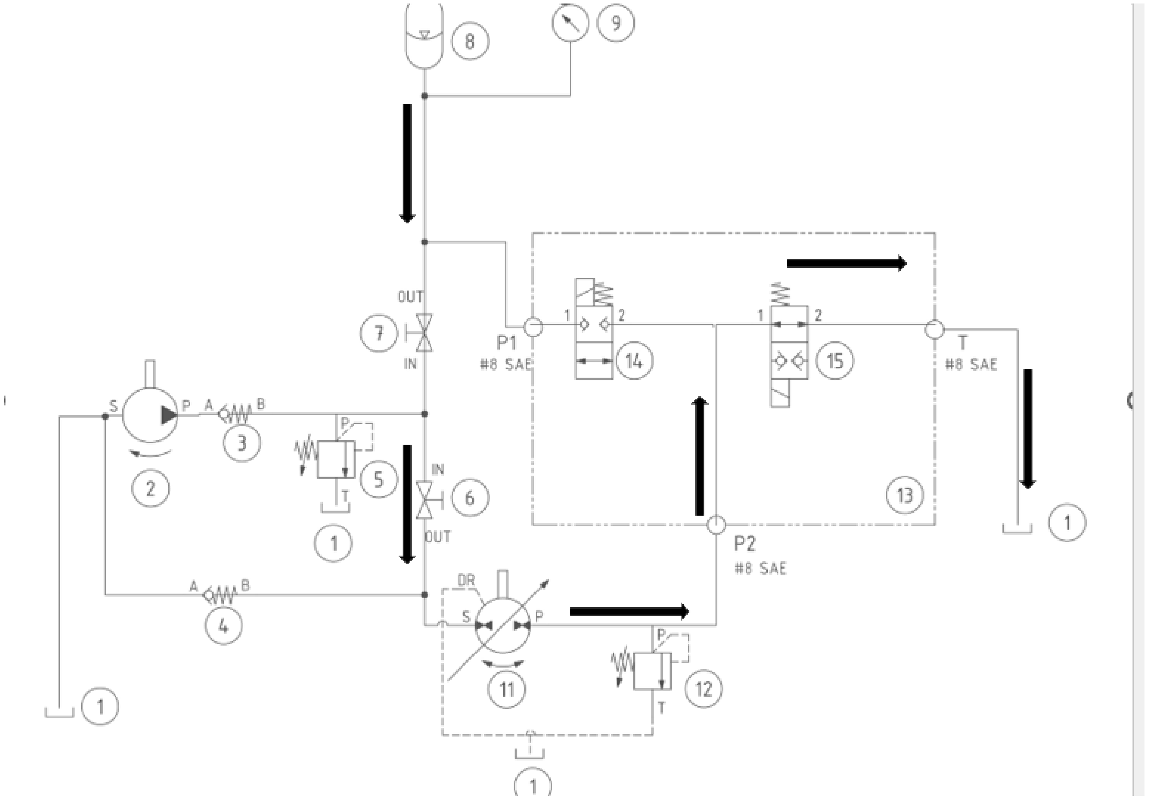
Pressurizing Accumulator



Regenerative Braking



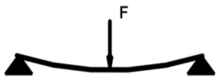
Discharging Accumulator



Equations

Formulas for calculating deflection at critical points

Supported at both ends



$$f = \frac{F * L^3}{48\,E * I * 10^4}$$

Total Load F

$$f = \frac{5}{384} * \frac{F * L^3}{E * I * 10^4}$$

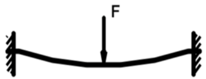
Fixed at one end

$$f = \frac{F * L^3}{3\,E * I * 10^4}$$

Total Load F

$$f = \frac{F * L^3}{8\,E * I * 10^4}$$

Fixed at both ends



$$f = \frac{F * L^3}{192\,E * I * 10^4}$$

Total Load F

$$f = \frac{F * L^3}{384\,E * I * 10^4}$$

In the formulas:

f = deflection in mm

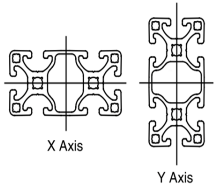
F = load in N

L = free profile length in mm

E = Modulus of Elasticity in N/mm^2

E_{Al}= 70,000 N/mm^2

I= Moment of inertia in cm^4



Example

Find the deflection for the following conditions:

80x40 Standard Profile (10-080), upright

I_x = 71.97 cm^4

m = 3.18 kg/m

L = 1000 mm

F = 50 N - concentrated load

No additional load other than profile weight

Calculate Profile weight (uniform load)

$F_U = m * L * g = (3.18 * 10^{-3}) * 1000 * 9.81 = 31.2$ N

Total deflection $f_{TOTAL} = f_{CONCENTRATED} + f_{UNIFORM}$

Supported at both ends:

$f = 0.021 + 0.008 \approx 0.03$mm

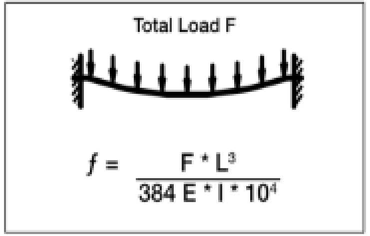
Fixed at one end:

$f = 0.331 + 0.077 \approx 0.041$mm

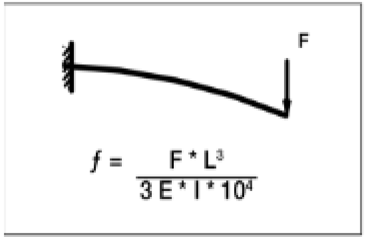
Fixed at both ends:

$f = 0.005 + 0.002 \approx 0.01$ mm

Design Calculations



Deflection between wheels
=1.2989 mm ≅ .0507 in



Deflection of pedal support
=.2 mm

F_1=1378.95 N
F_2=400.34 N
L_1=1857 mm
L_2=292.86 mm
Ix=97.6617 cm^4
Iy=25.2917 cm^4
E_{Al}=70,000 N/mm^2

Design Calculations

$$\frac{F \times V}{33000}$$ Horsepower =.91HP

F = Force (lbs)
V = Velocity (ft/min)

$$\frac{HP \times 5252}{N}$$ Torque =19.11LbFt

T = Torque (LbFt)
HP = Horsepower
N = Speed (rpm)

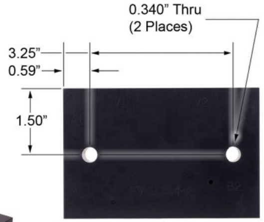
$$GPM = \frac{CIR * RPM}{231}$$ Flow Rate =.726 GPM

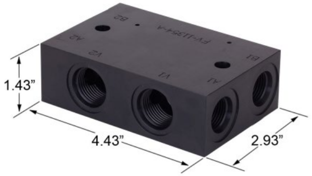
$$V = \frac{0.32 * GPM}{NetArea}$$ Fluid Velocity =1.18ft/sec

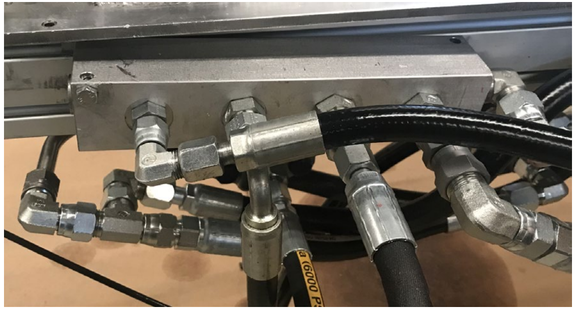
W=310 lbf(rider+vehicle)
μ=.008
Θ=1.718° (3% downgrade)
Vmax=27 mph
ω_{pump}=250rpm
Fmax= 12.63 lbf
Fmin= -6.815 lbf
CIR=.671 (cubic inches/rev)

Manifold

- First time a manifold has been used on a CSU bike
- Two used: One for tank return, one for solenoid implementation

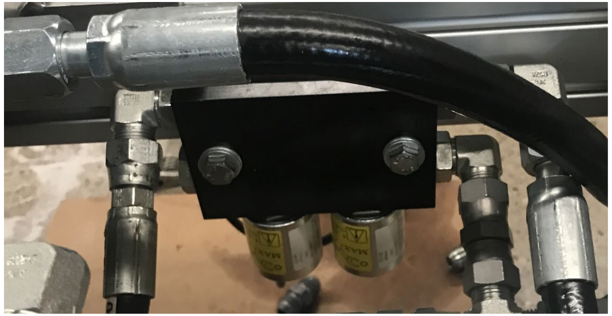






Solenoid Valve

- Streamlines design by removing manual valves
- Not present on several previous CSU bikes



Lessons Learned

- Proper thread type is crucial
- Be as proactive as possible while waiting for parts
- Ensure that enough oil is in the tank to reach high pressures
- Try a simpler circuit as a “proof of concept”
- Wiring the solenoids
- Difficulties we overcame:
  - Some parts arriving later than expected
  - Deadlines
  - Frame integrity
  - Steering mechanism & front wheel issues
  - Wiring the electrical components
- Insufficient testing was performed due to lack of time
  - Unable to test efficiency before shipping

Mentorship

- We benefited from plenty of guidance throughout the year
  - Josh Scarborough helped us with part orders and circuit design
  - Last year's team offered advice on getting started
  - Professor Kozul supported us throughout and assisted in assembly and testing

Thank You
Questions?