Four Quadrant Multi-Fluid Pump-Motor

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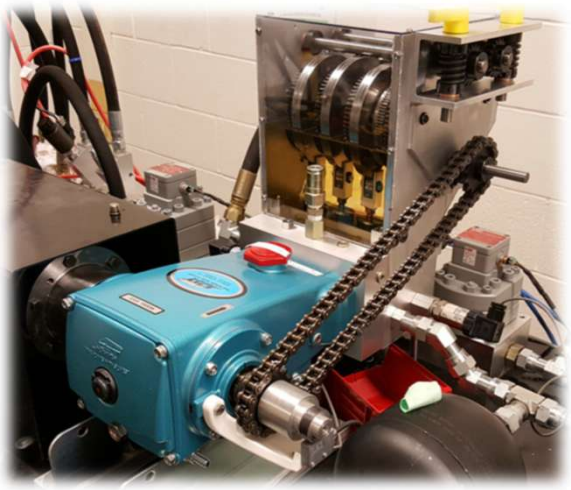
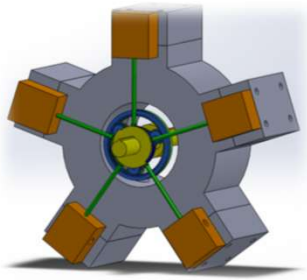
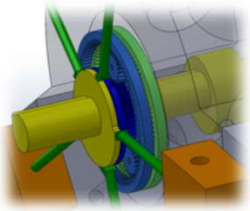
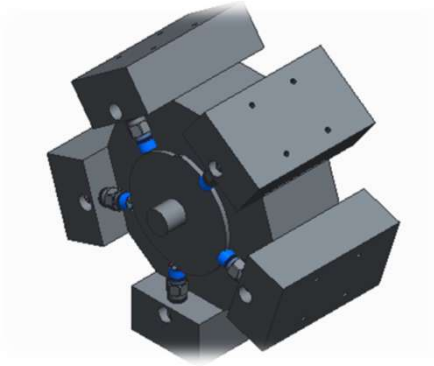


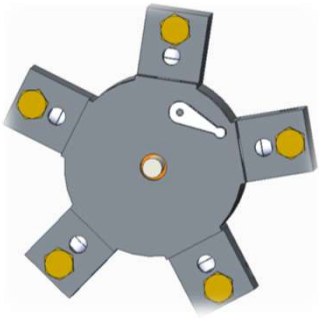


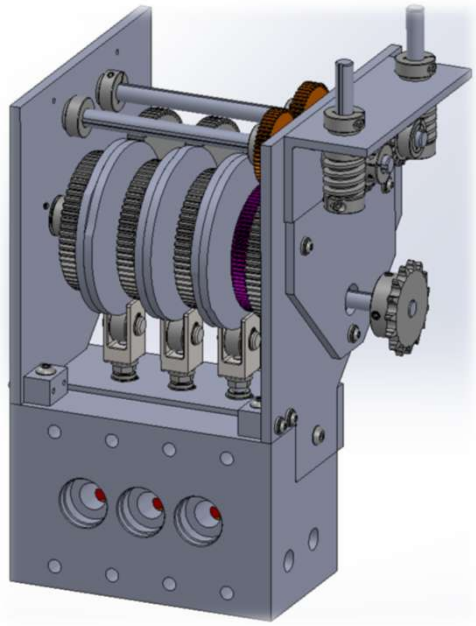


Overview



- Potential of a four-quadrant multi-fluid pump/motor?
- How we are achieving this?
- What are the benefits?
- Results from the first mechanically actuated prototype.
- Moving forward…

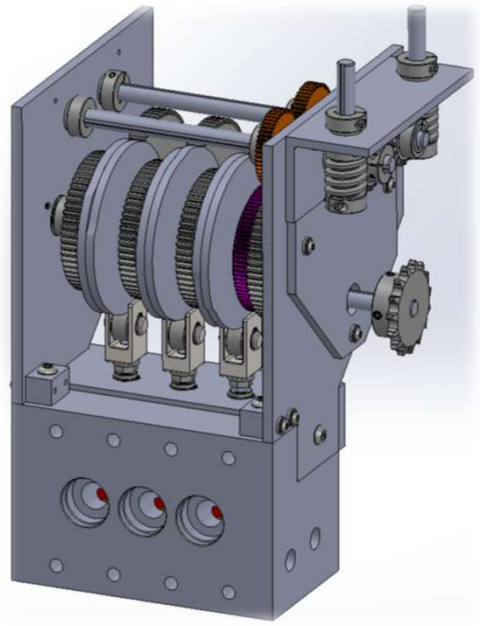




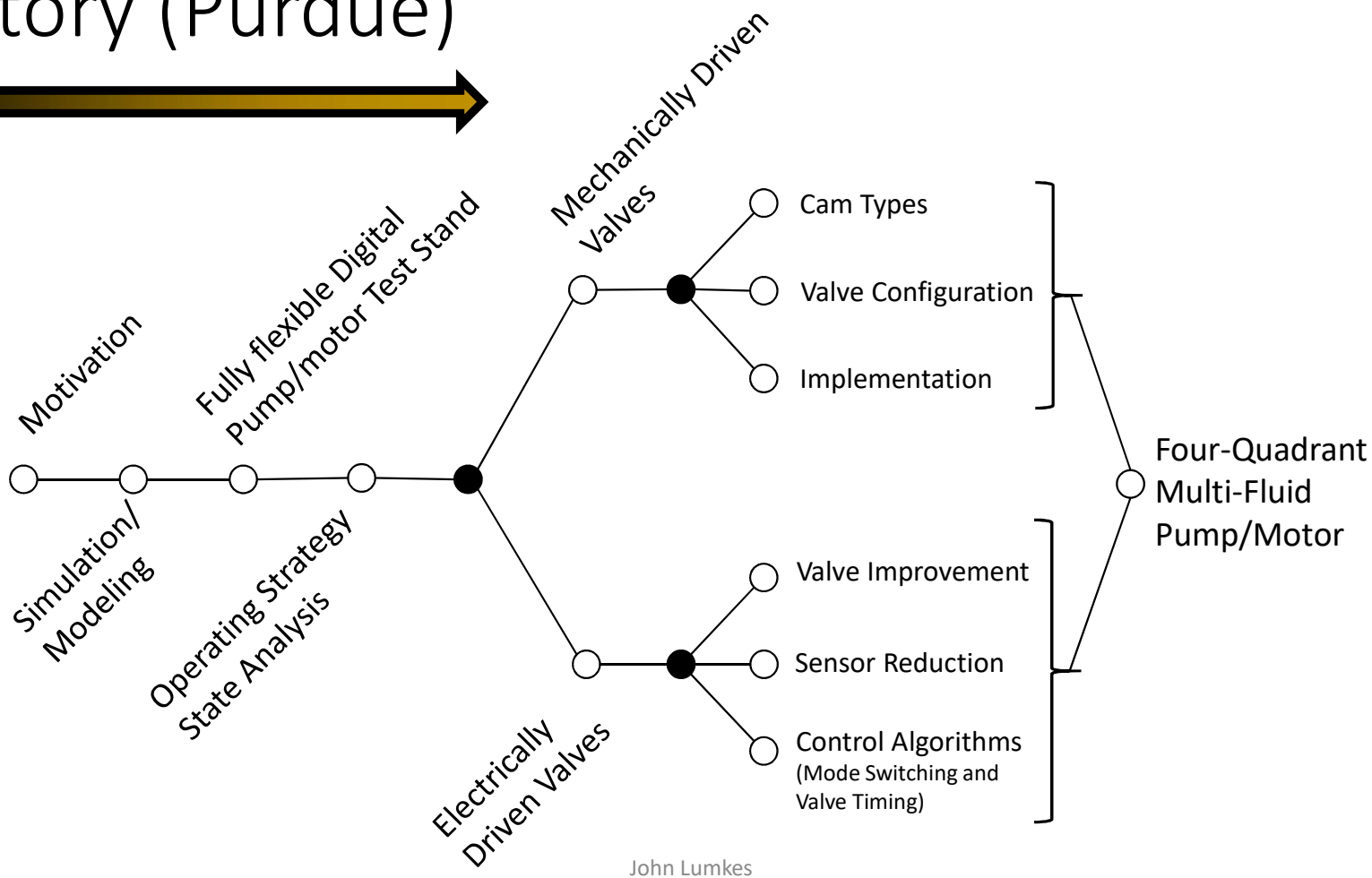
Mechanically actuated valve prototype

Background

- Digital Four Quadrant Multi-fluid Pump/Motor
- Digital: utilizes digital displacement control
  - On/off valves at inlet and outlet of each piston
- Four-quadrant: capable of pumping and motoring each in CW and CCW rotation
- Multi-fluid: pump lubrication does not depend on operating fluid



History (Purdue)

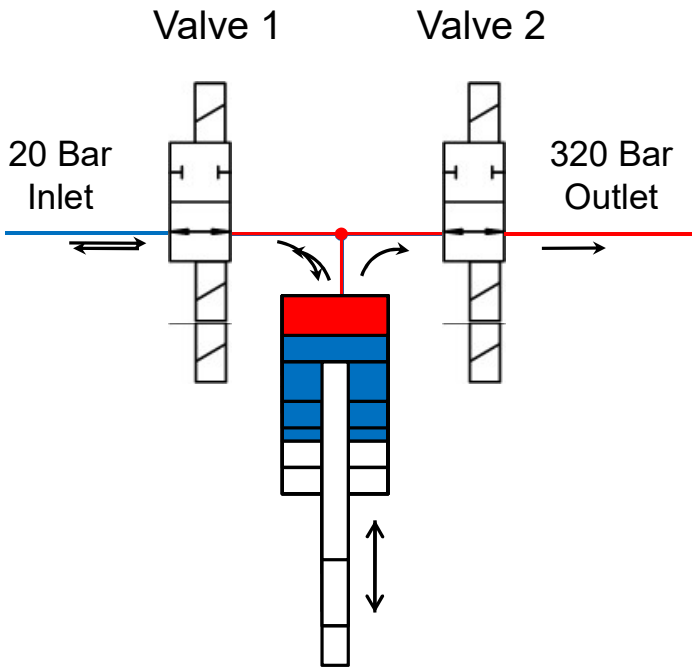


Benefits

- General digital pump/motor advantages
  - Eliminates valve plate losses
  - Leakage scales closely with displacement
  - Pumping of non-conventional fluids (water)
  - On/Off valves can open against high pressure
  - Four quadrant operation
  - Self starting in motoring
- Specific advantages of proposed approach
  - No need for pilot pressure
  - Higher efficiency
  - Simple, single lever, robust control of displacement
  - No electrical energy needed
  - Lower cost

Operating Strategies

- **Flow Diverting**
  - Excess flow taken into the chamber is diverted back to the low pressure port
- **Flow Limiting**
  - Amount of flow taken into the chamber is limited to the desired flow
- **Sequential (Diverting or Limiting)**
  - Individual cylinders are operated at full or zero displacement



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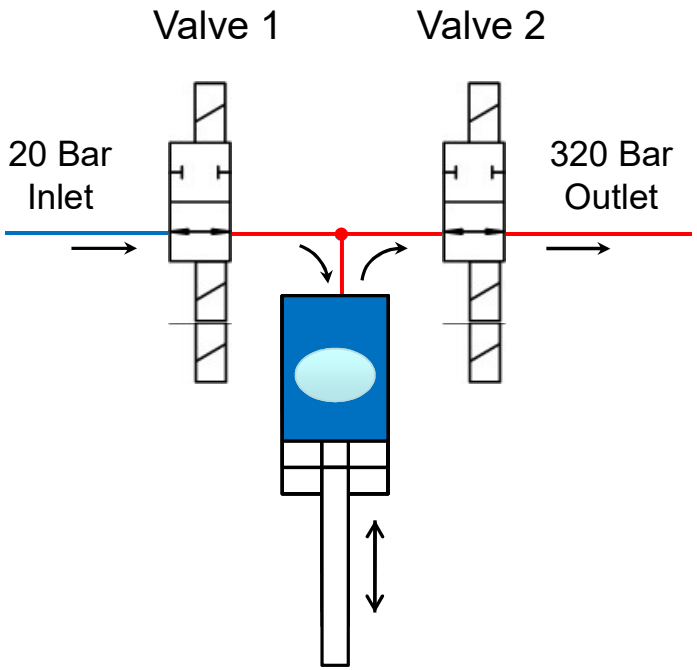
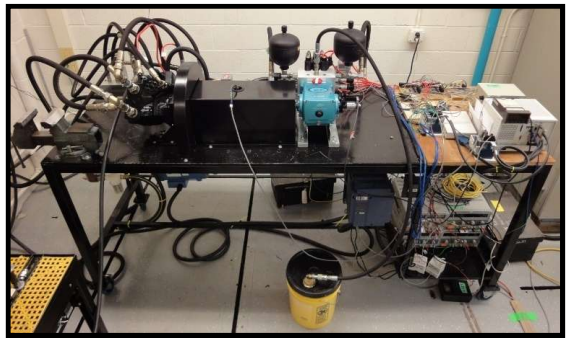
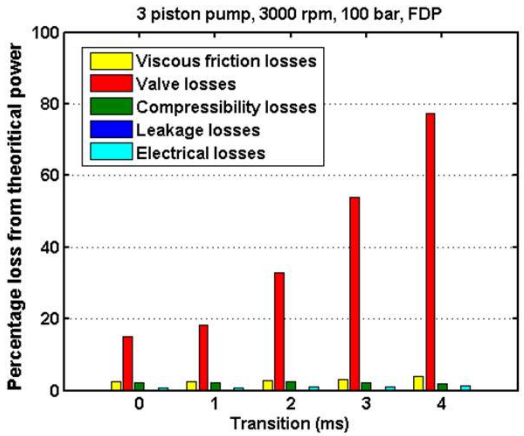


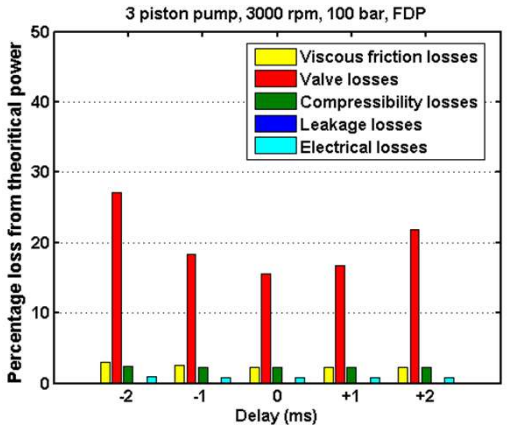
Digital displacement control

Electrically Actuated Valves (EAV)

- Valves actuated using solenoids
- Low repeatability
- Requires additional sensors and embedded controls

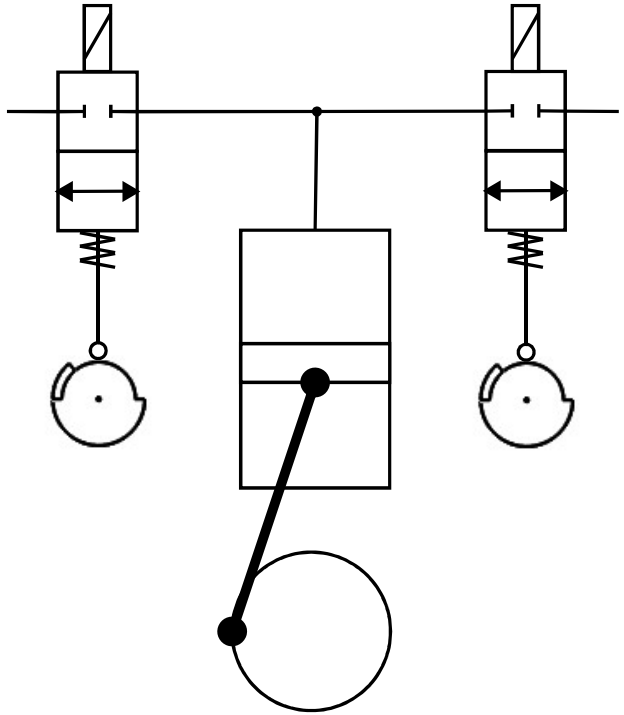




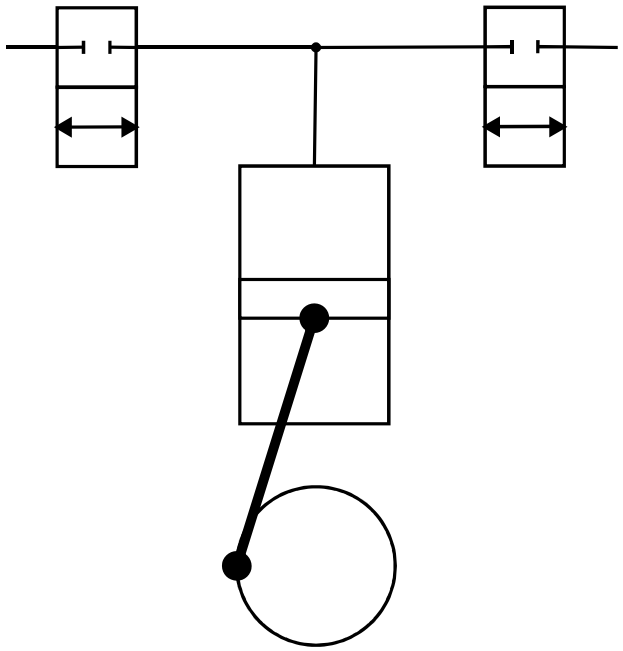


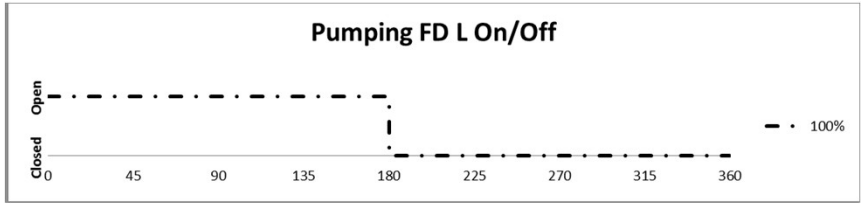
Mechanically Actuated Valves (MAV)

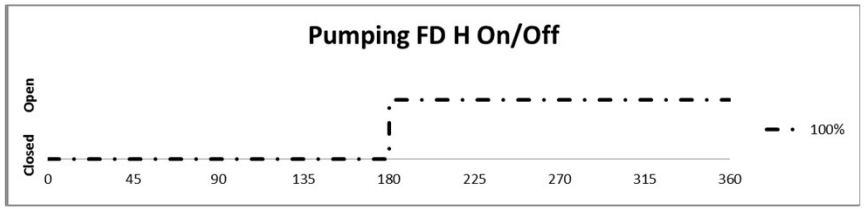
- MAV Advantages
  - Fast actuation
  - No electrical energy needed
  - No additional sensors and embedded controls
  - Actuation repeatability is increased
    - Critical for efficiency

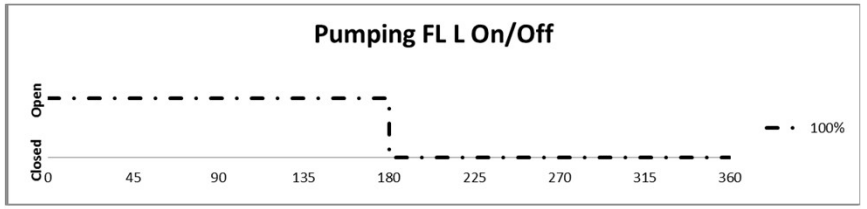


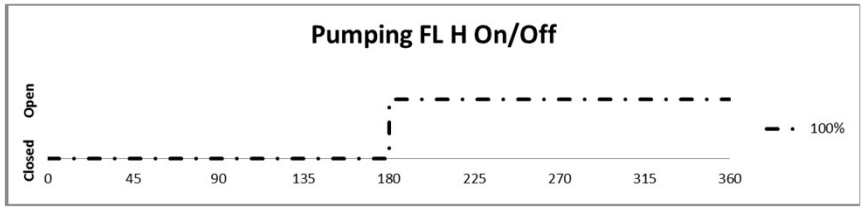
Operating Strategy State Analysis



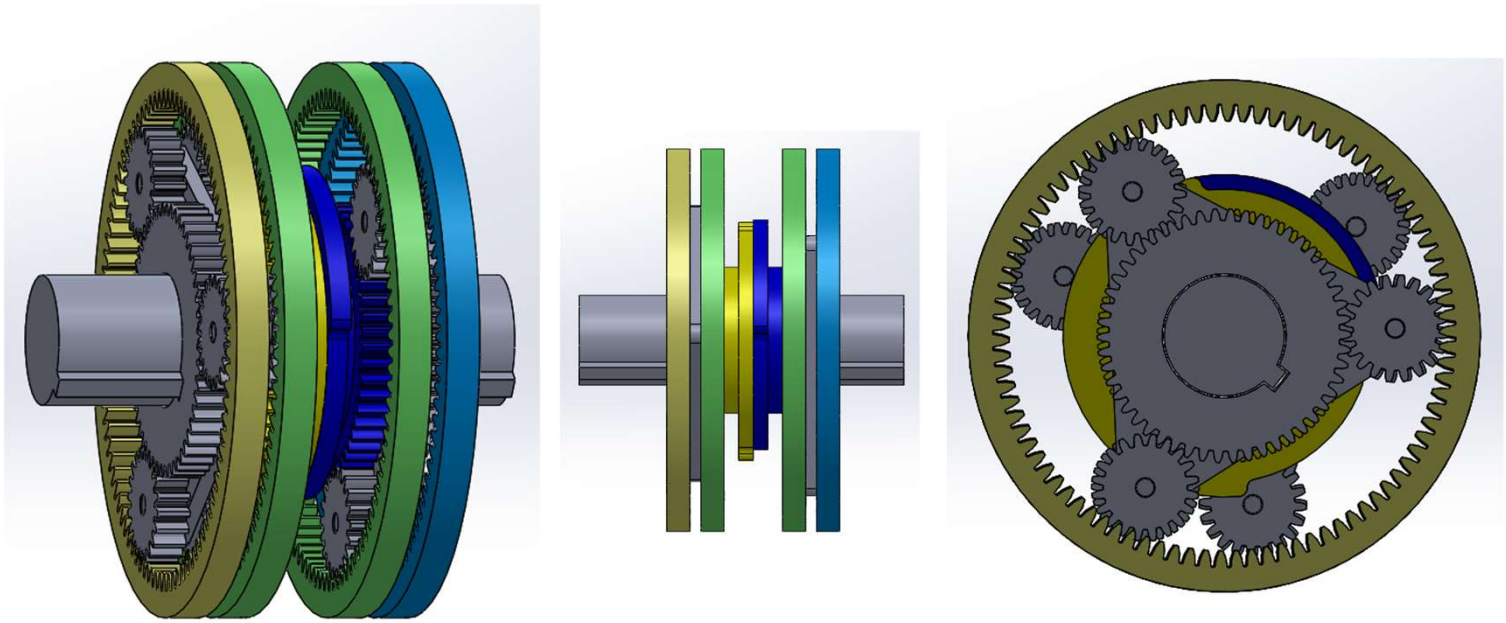








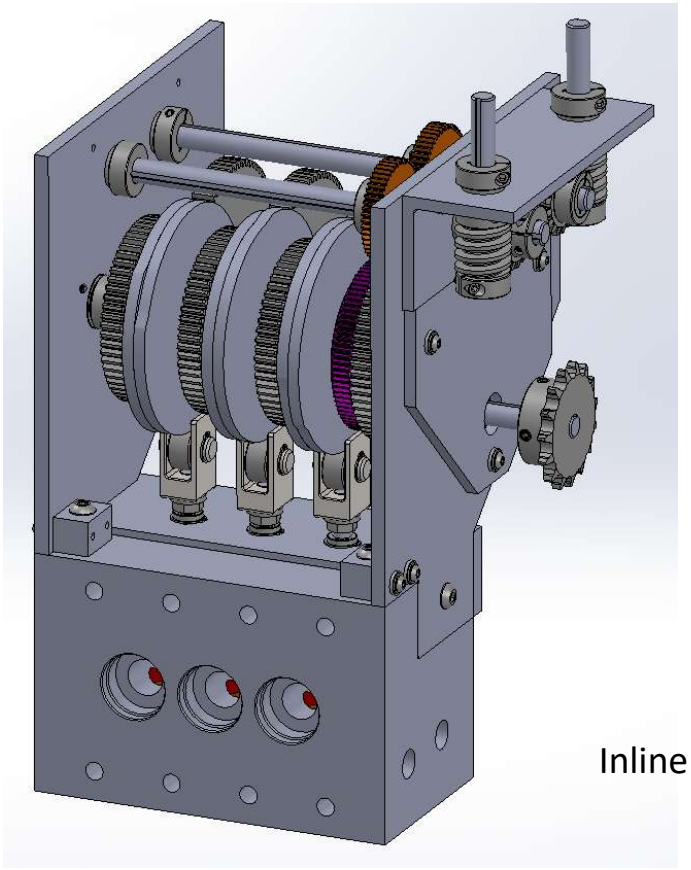
Cam Phasing

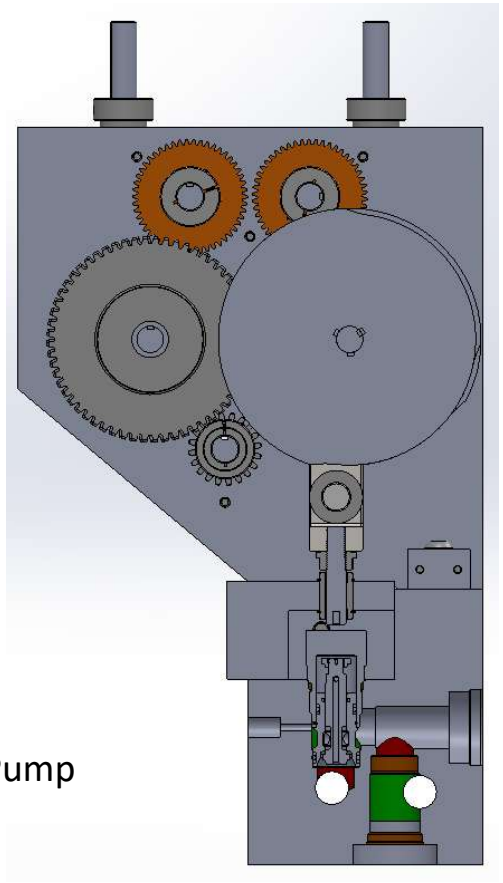


Planetary Gearsets for Valve Opening/Closing

(P/M Shaft connected to sun, cam masks connected to planetary carrier, adjustable rings)

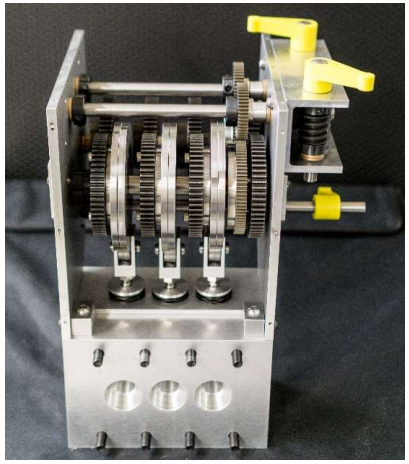
Implementation

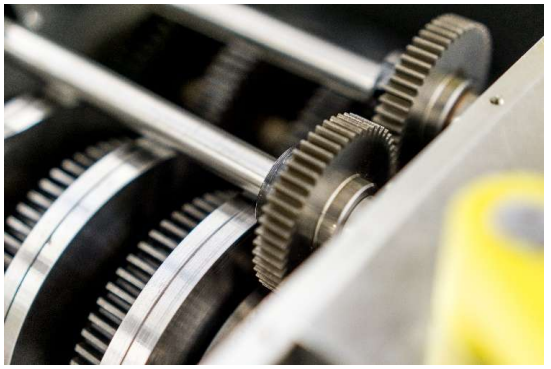


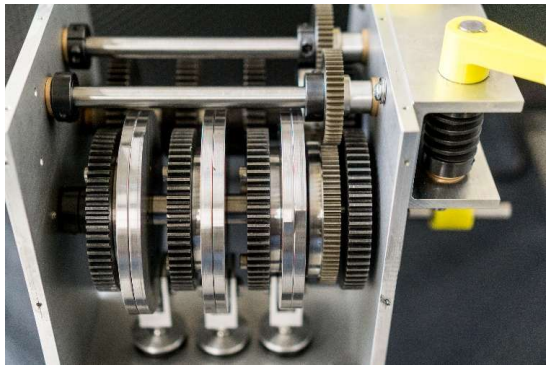


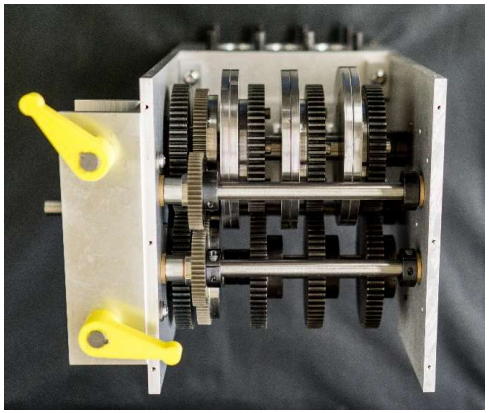
Inline Piston Pump

Prototype



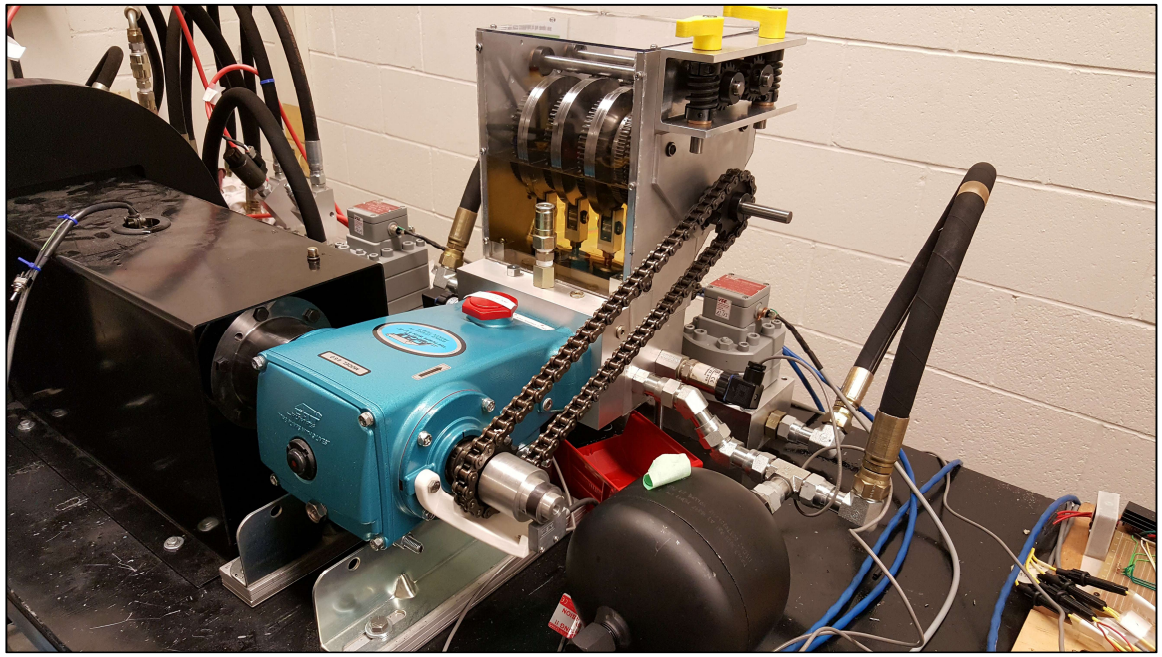






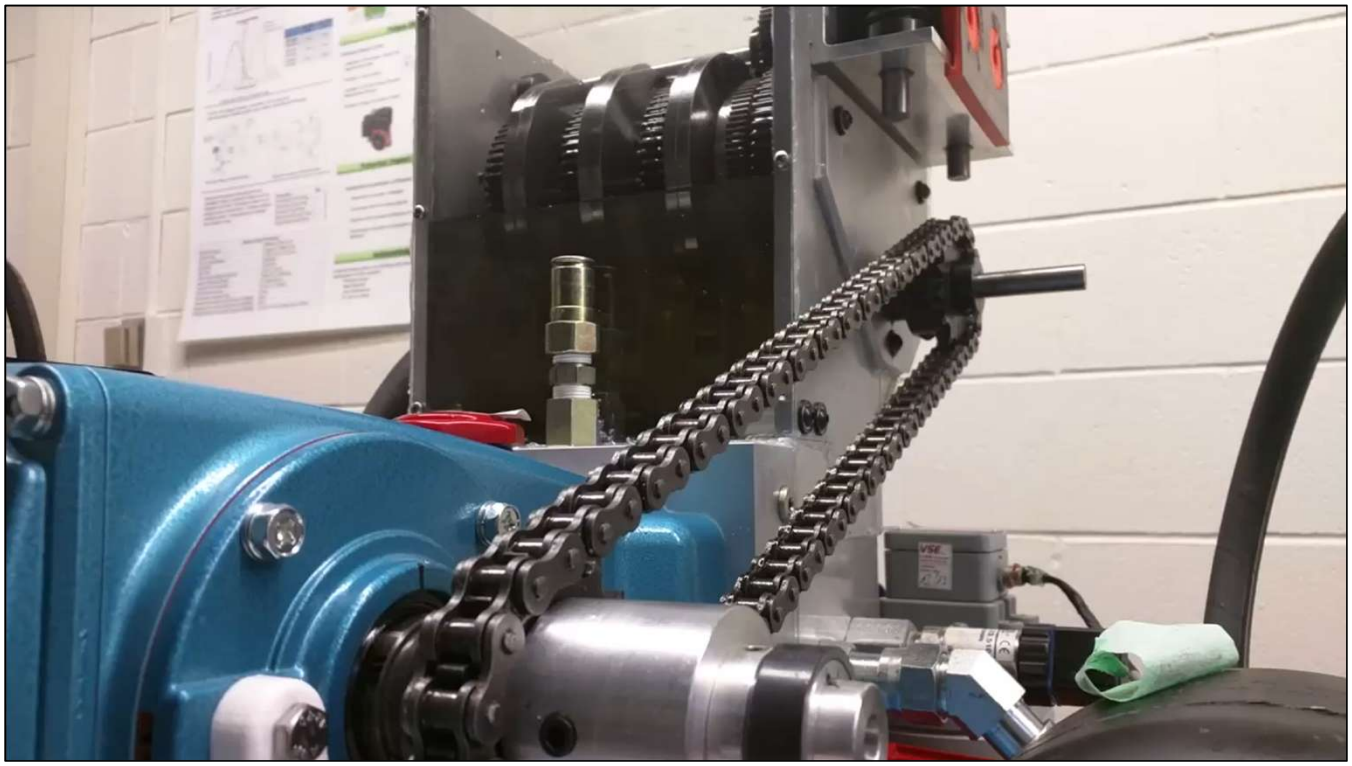
Experimental Test Stand

- Multi-piston digital pump/motor test stand



- 3-piston digital pump
- One on/off valves per piston
- One check valve per piston
- Three 2,000 Hz pressure transducers

Experimental Testing



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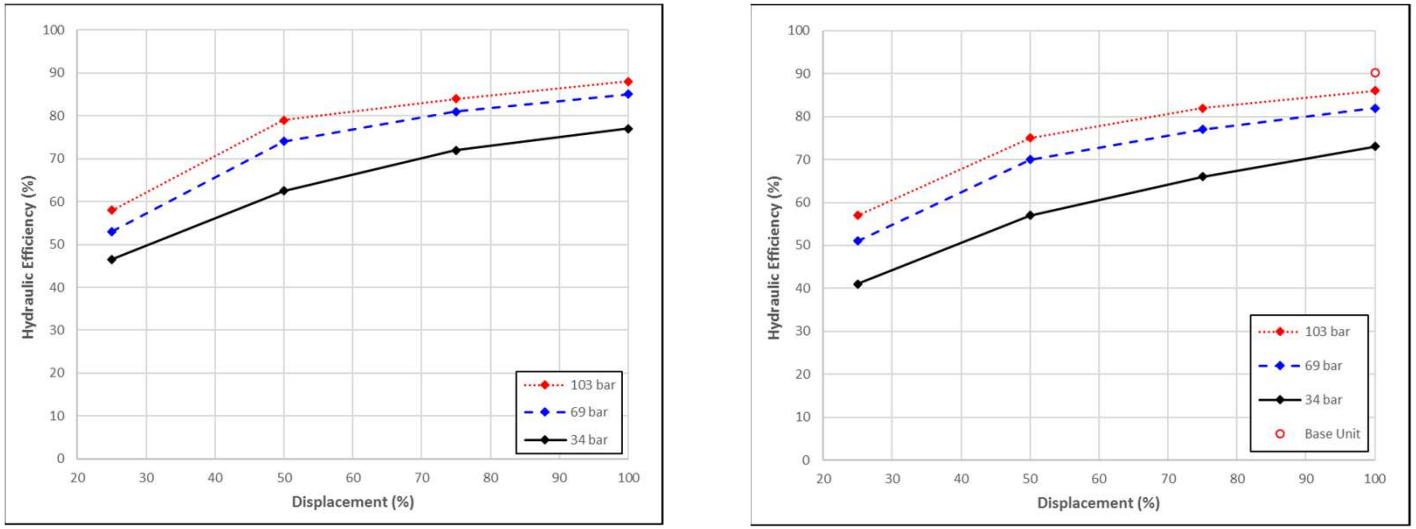
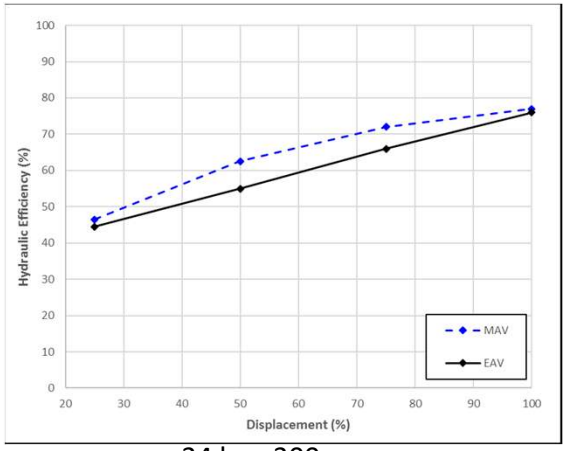
Results for Mechanical Actuation

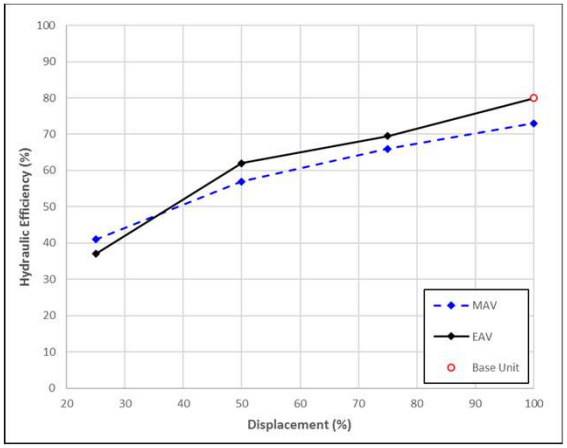
- Partial flow diverting shown here
- Efficiency does not fall below 40%



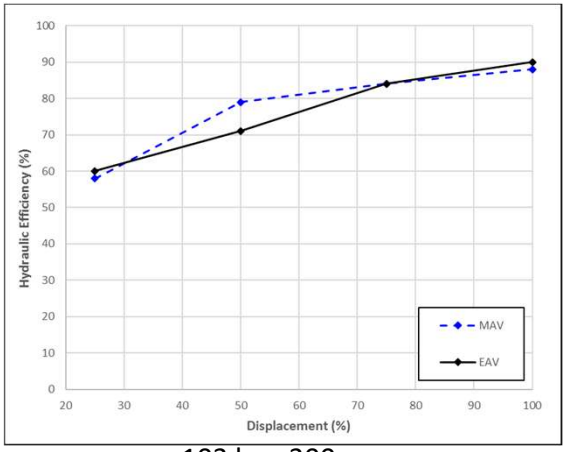
Overall hydraulic efficiency for pumping at 300rpm (left), 500rpm (right)



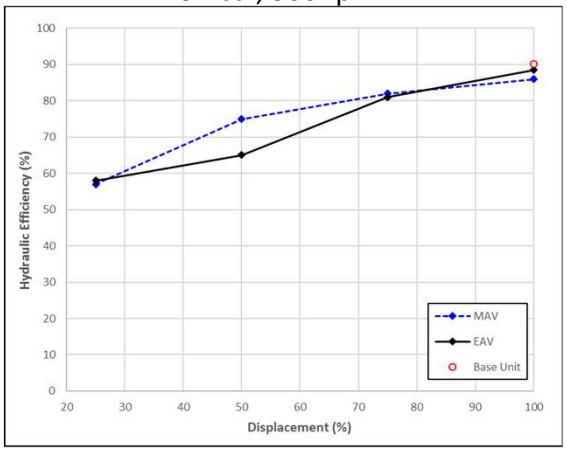
34 bar, 300 rpm



34 bar, 500 rpm



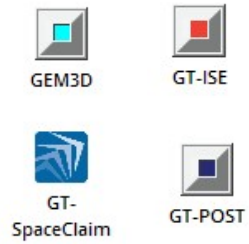
103 bar, 300 rpm



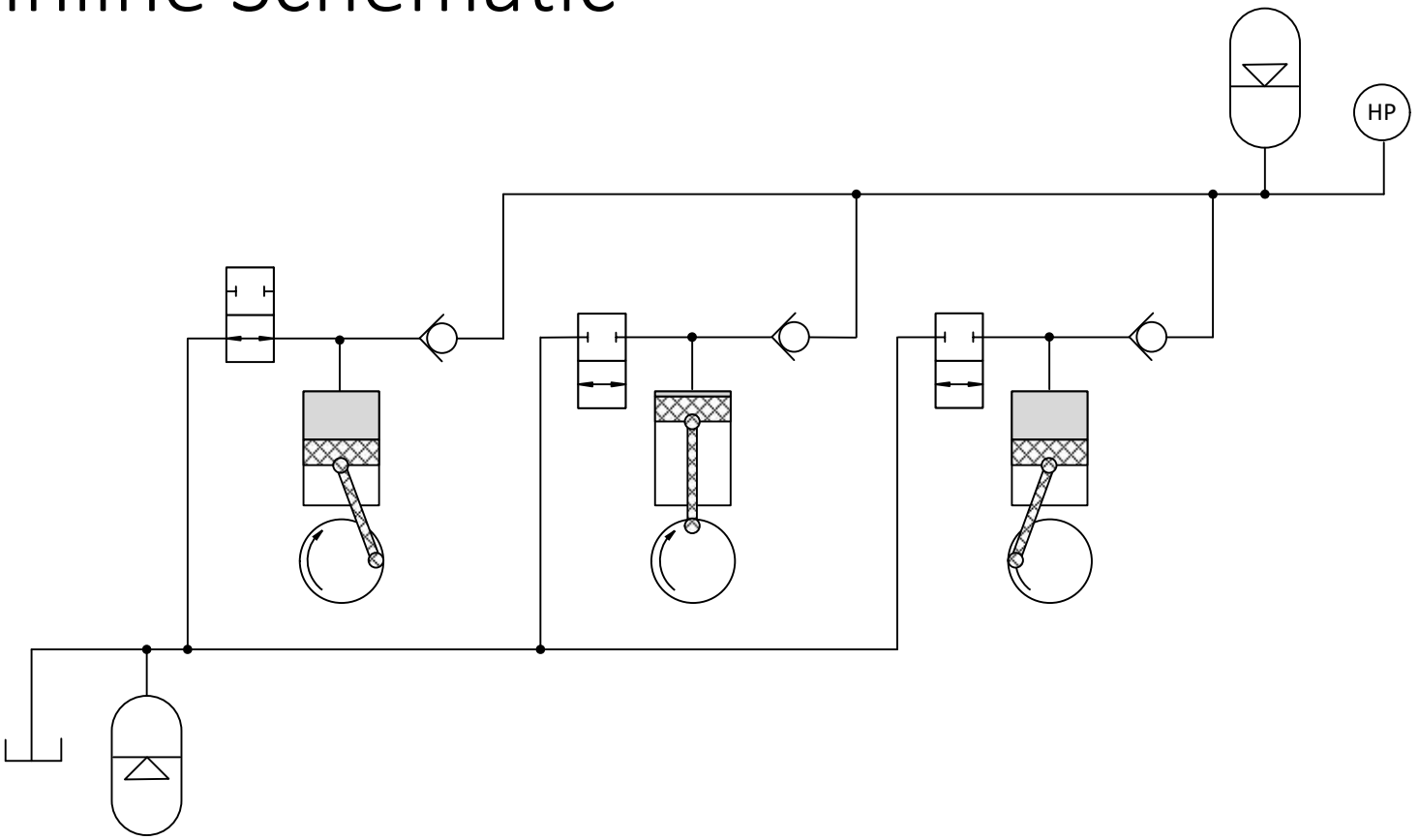
103 bar, 500 rpm

GT Suite Overview

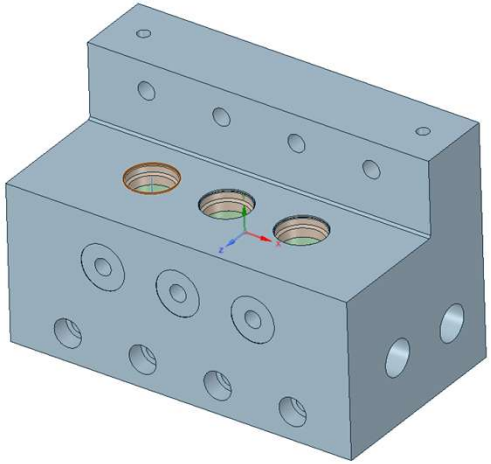
- 1D multi-physics system simulation software
- GT-Suite Tools
  - CAD modeling and preparation
  - Converting 3D CAD model into GT model
  - Model building and run control
  - Post processing
- Hydraulics applications
  - System and component level models
  - Existing piston pump and valve component templates
  - Accurate pressure wave dynamics
  - Advanced features such as DoE and optimization



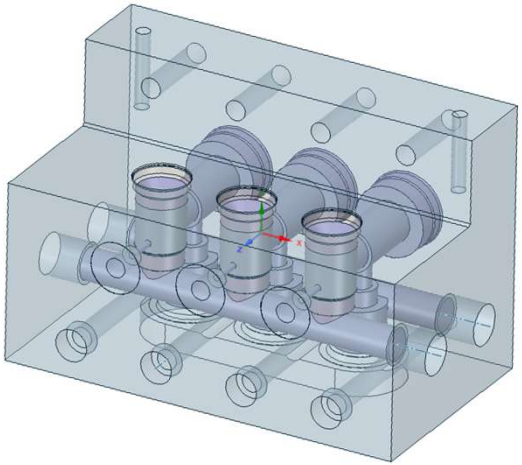
MAV Inline Schematic



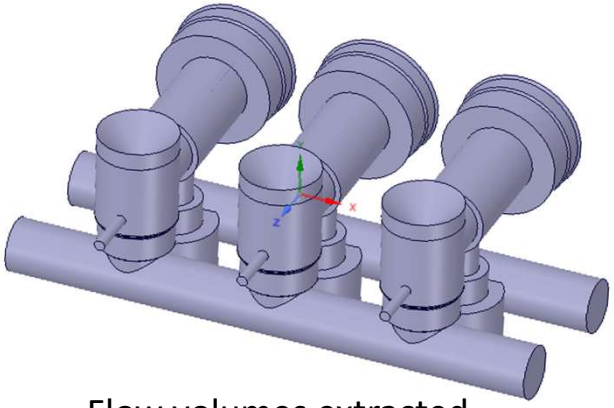
CAD Model Preparation



Solid block

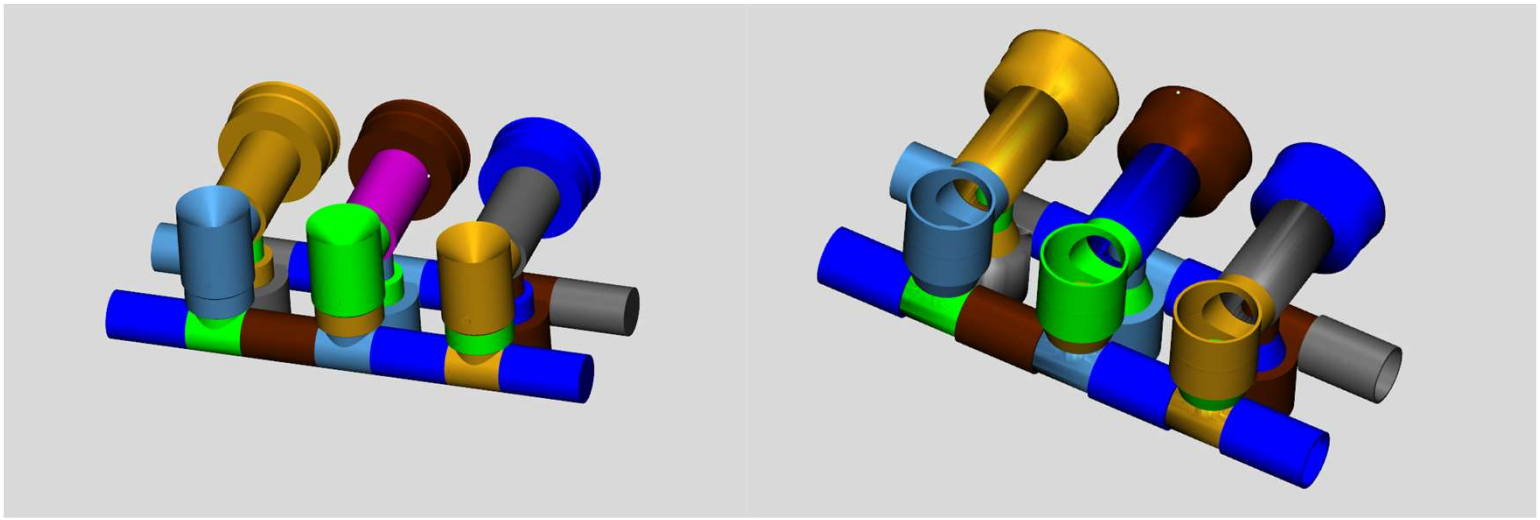


Flow volumes selected



Flow volumes extracted

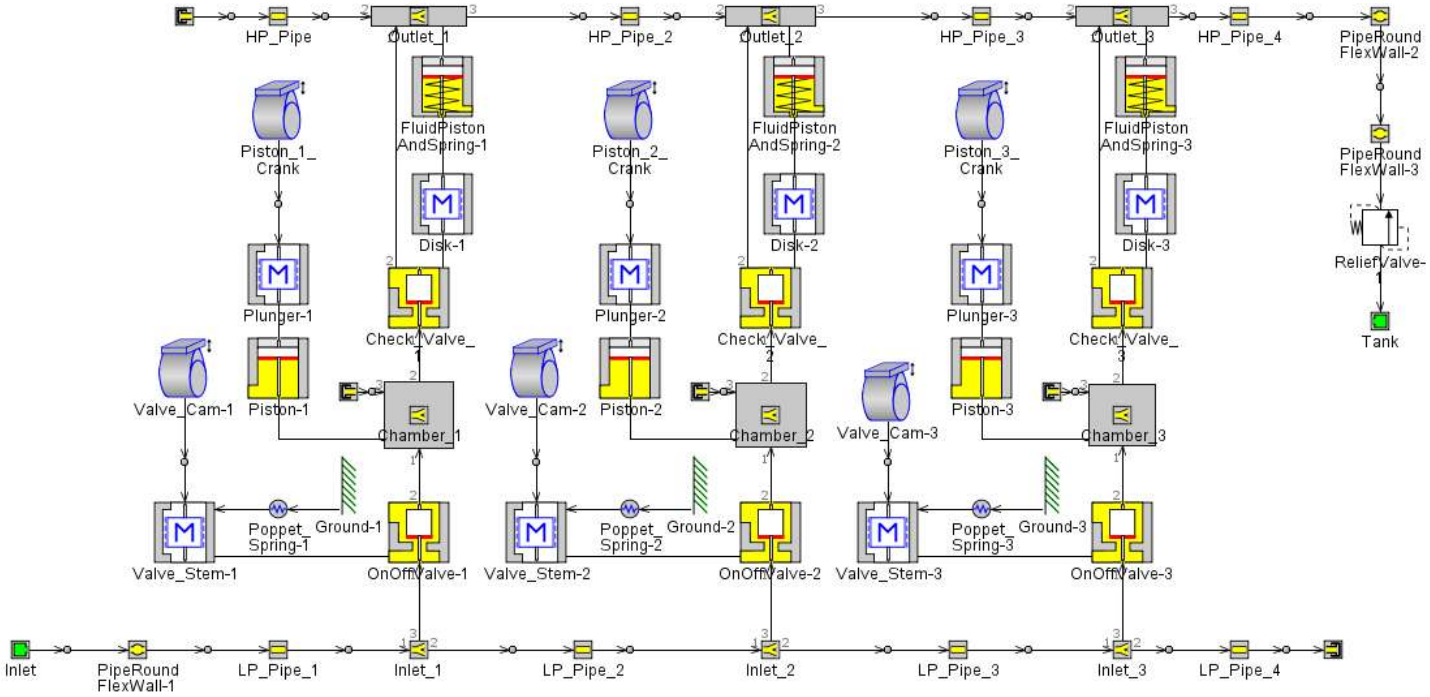
Converting to GT Components



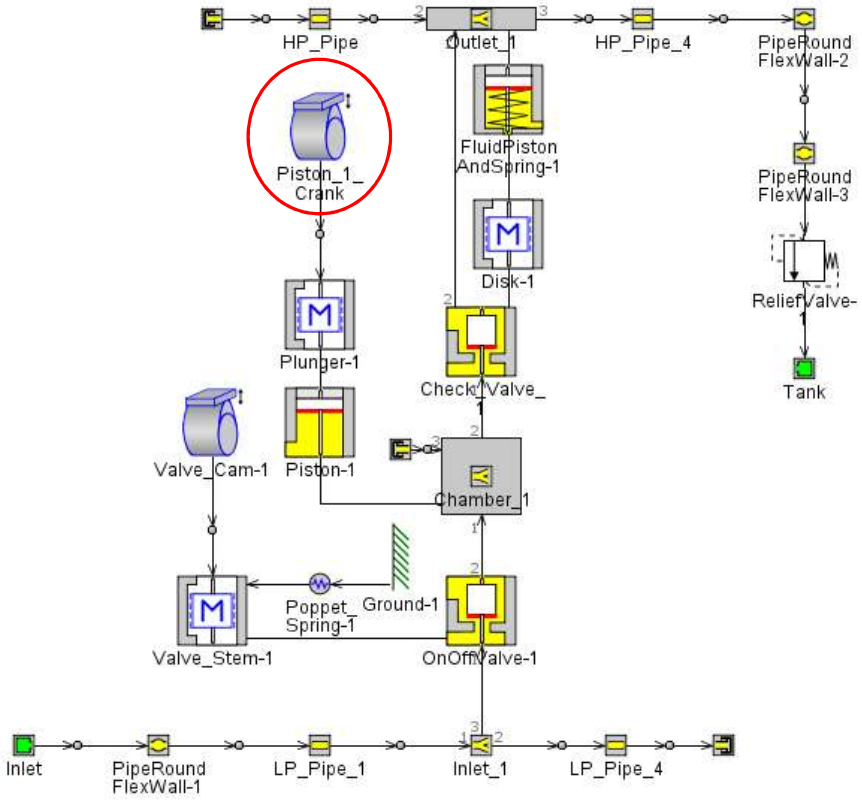
Split into individual parts

Converted into pipes and flow-splits

MAV Inline Simulation

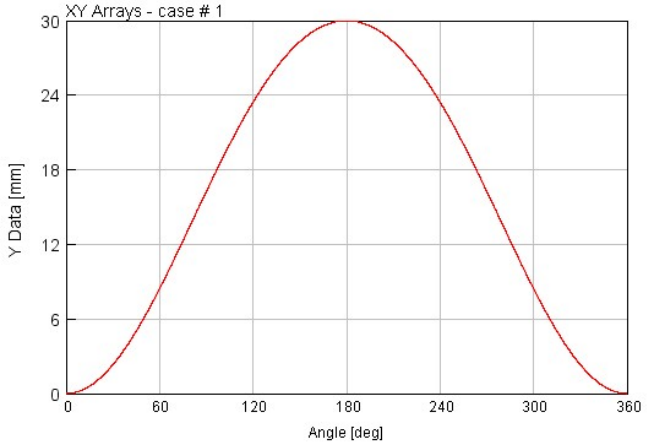


One Piston Simulation

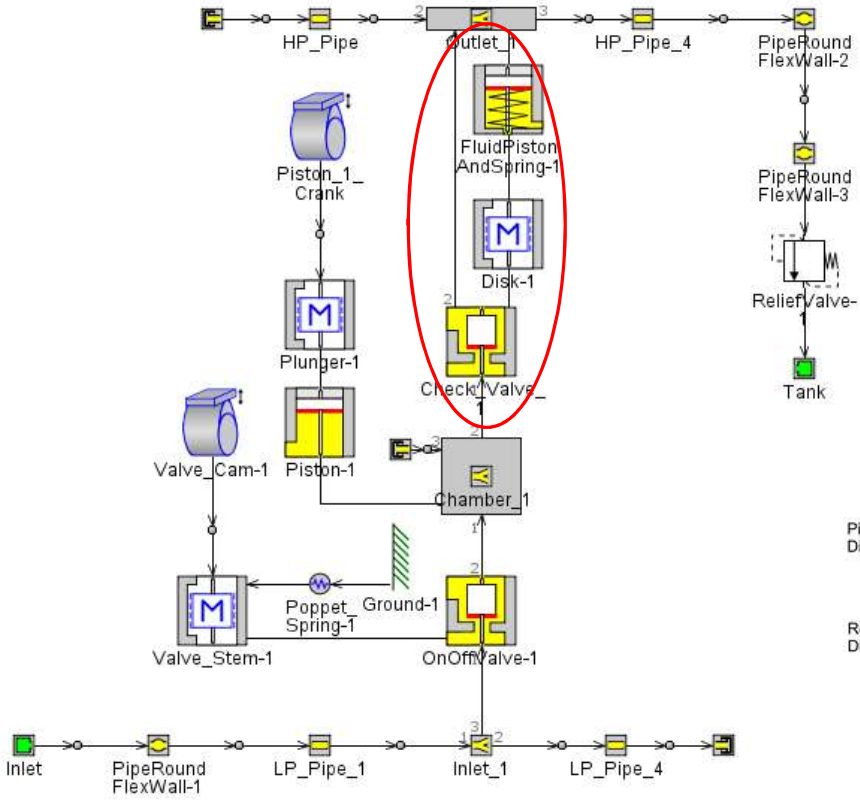


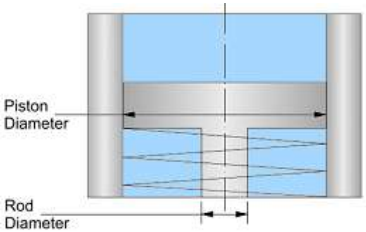
Piston crank-slider input

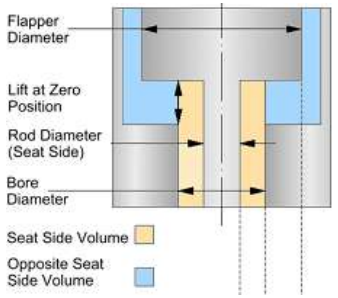
- Angle and speed defined by main driver
- Piston stroke angle profile



One Piston Simulation



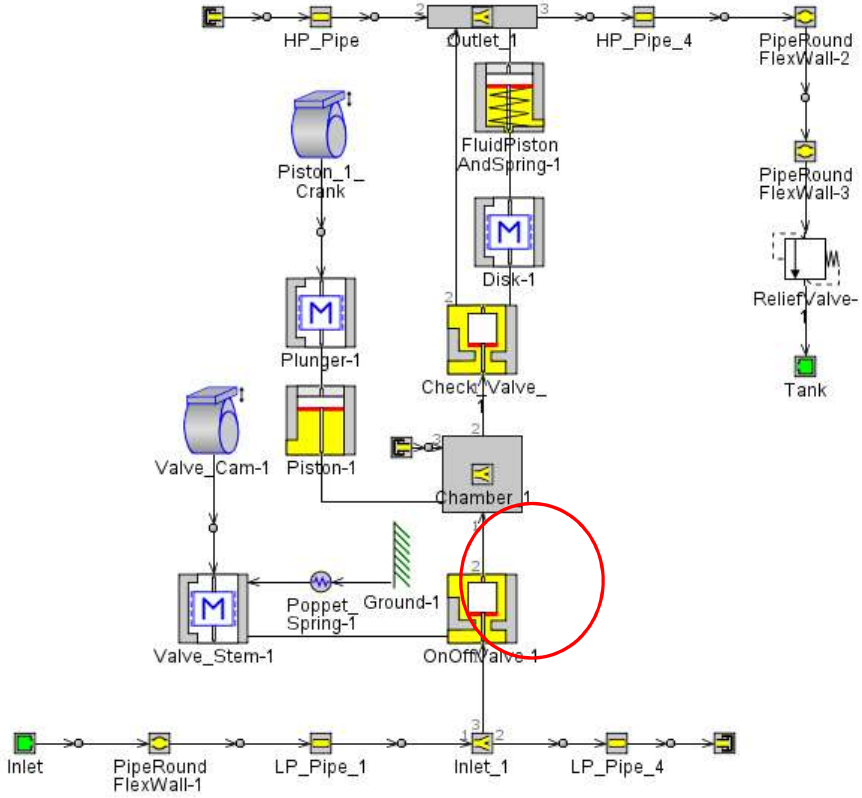




Check valve

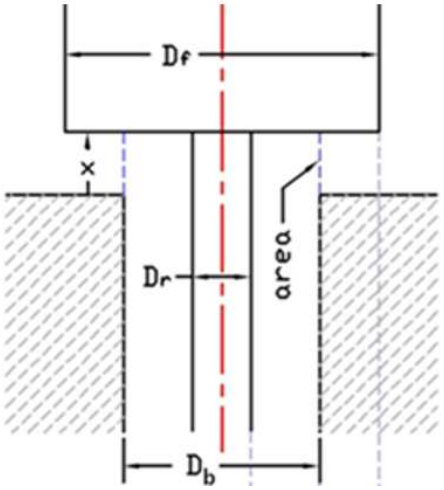
- Flapper disk dimensions
- Spring properties

One Piston Simulation

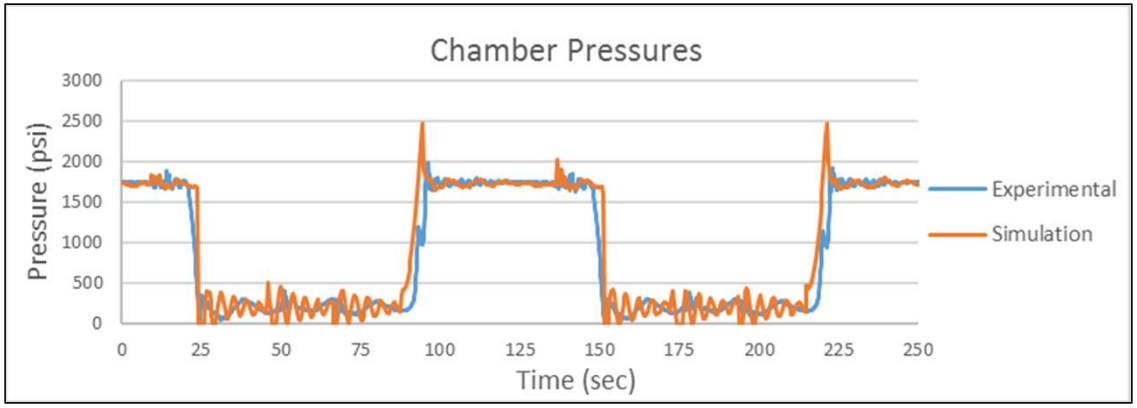


On/off valve

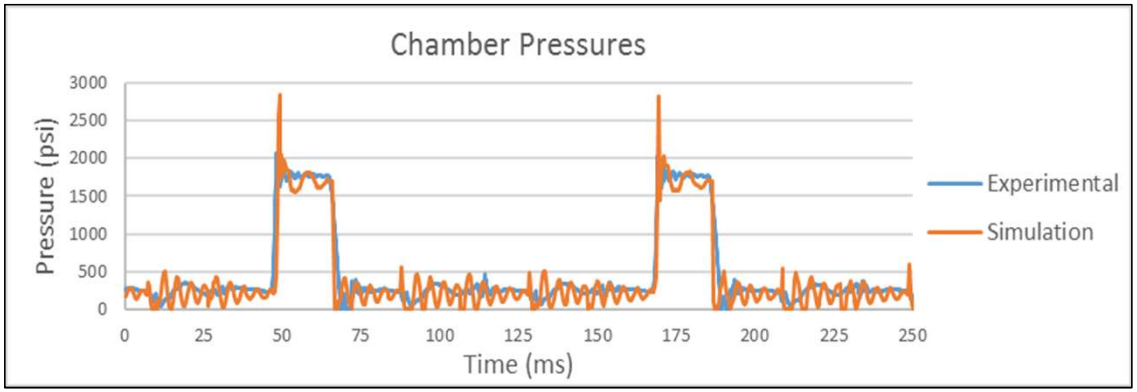
- Valve opening area
- Poppet parameters



MAV Inline Simulation

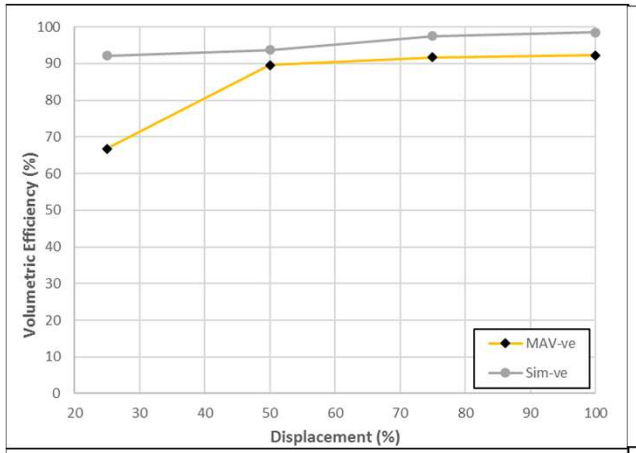


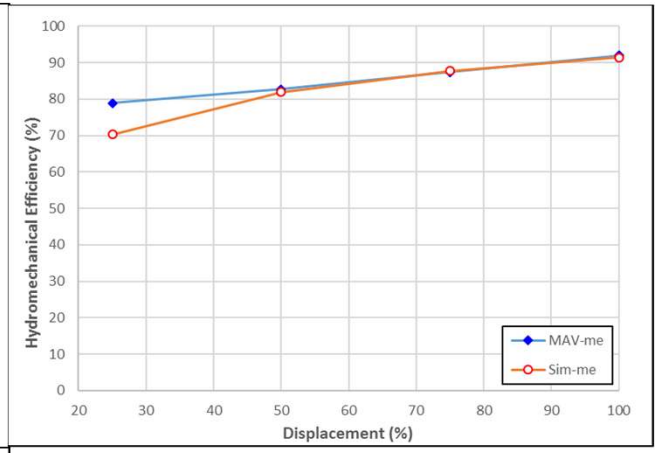
103 bar, 500 rpm, 100% displacement

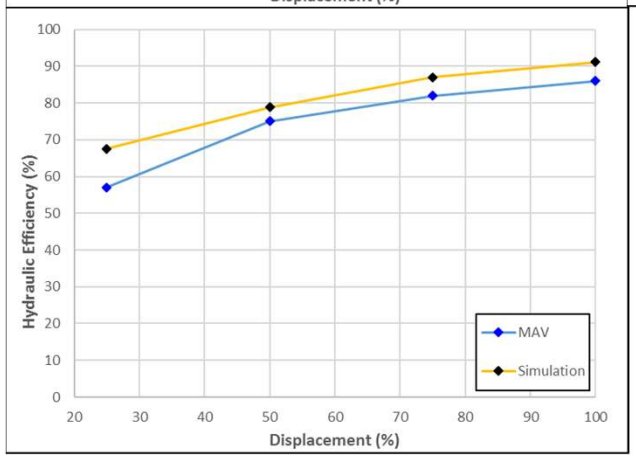


103 bar, 500 rpm, 100% displacement

Inline Simulation Results







Efficiency plots for 1500psi, 500 rpm

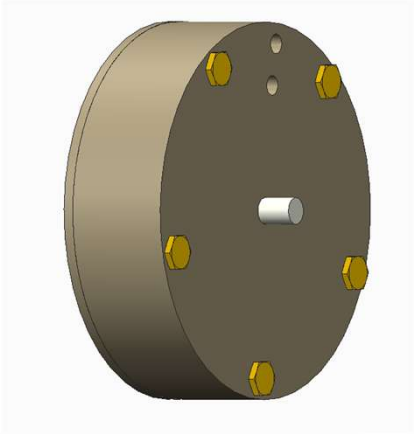
- Top Left- Volumetric Efficiency
- Top Right- Mechanical Efficiency
- Bottom- Total Efficiency

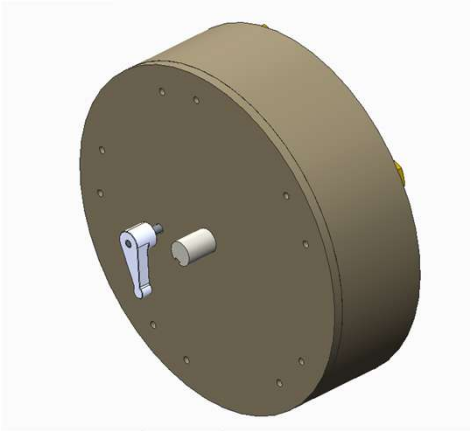
Next Generation MAV

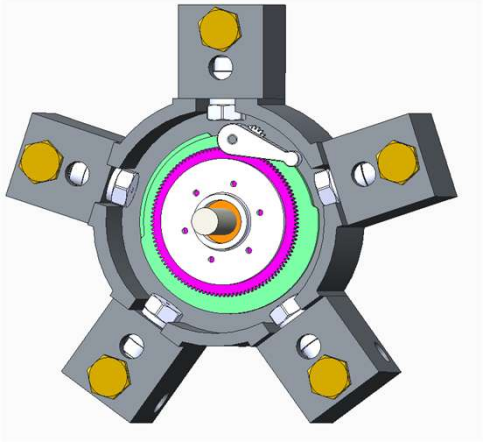
- Optimal design, open-ended approach
- Requirements
  - One cam assembly for all pistons
  - Minimal gearing
  - Smaller physical size
  - Four quadrant capability

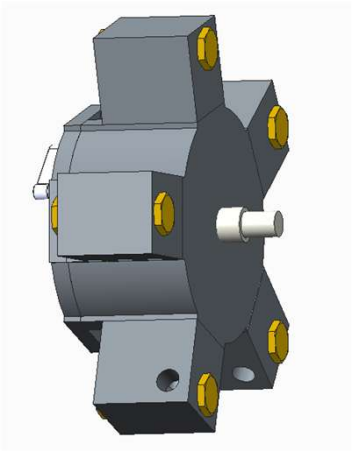
Radial Piston Orientation

- Benefits
  - Access to valves
  - Thru-shaft
  - Modular and compact design
  - Fewer moving parts

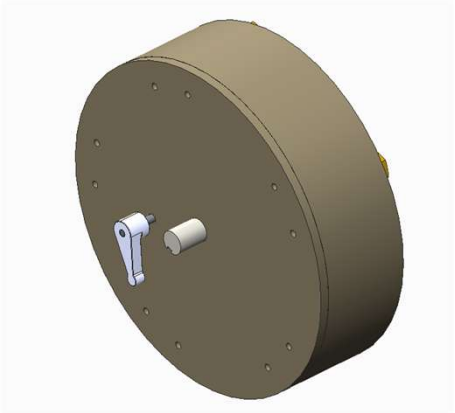


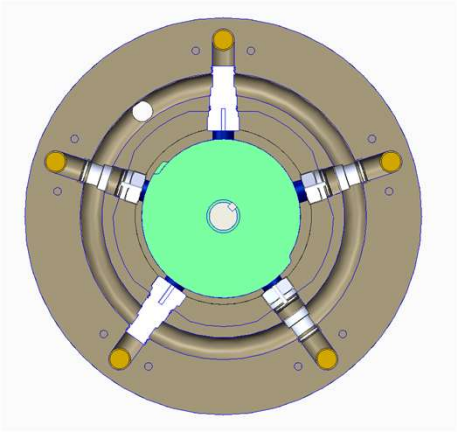


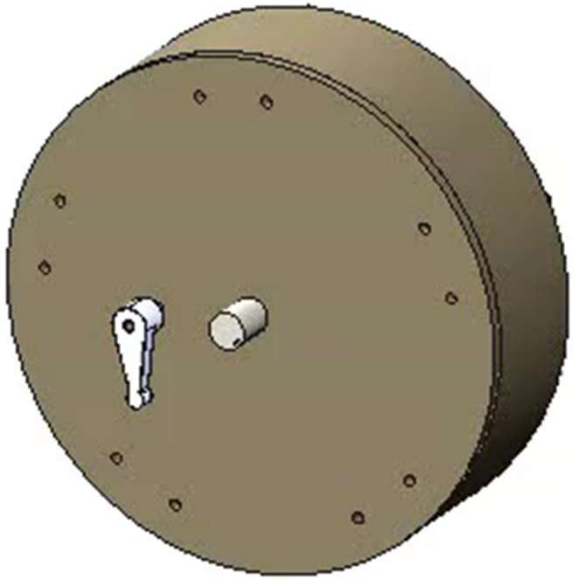


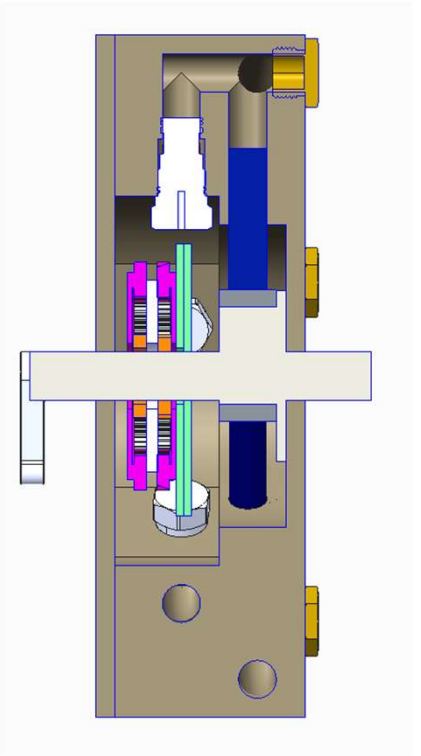


Radial Piston Orientation

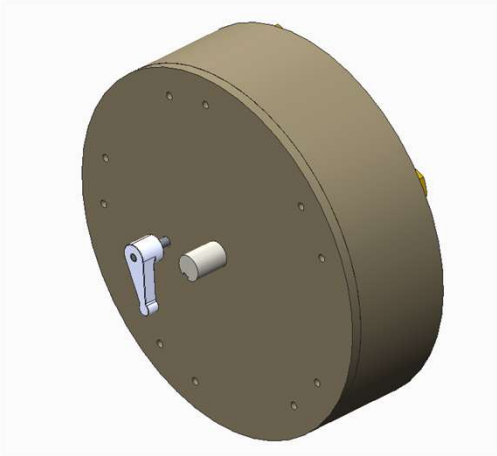


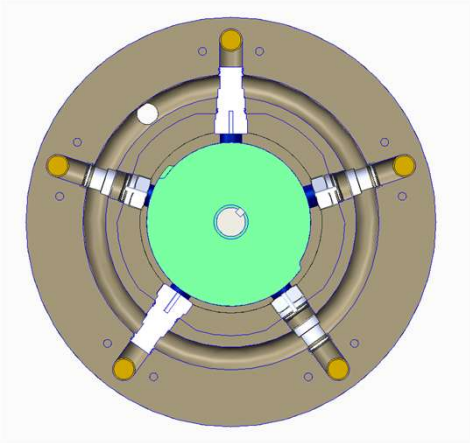


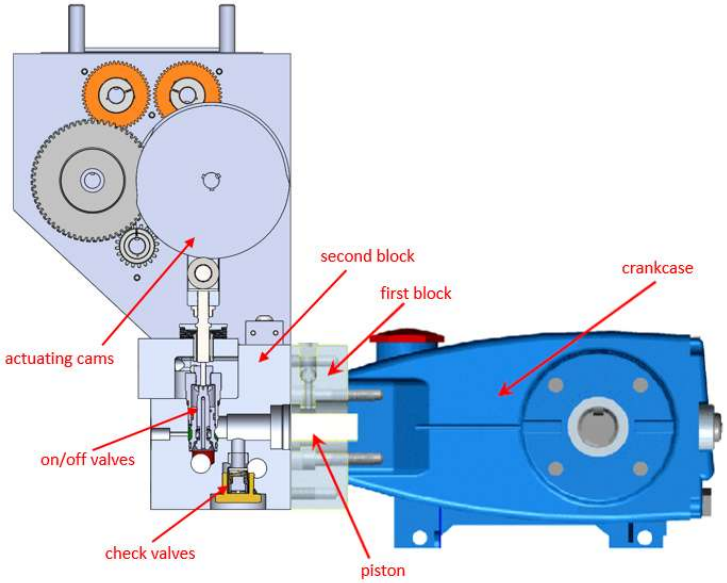




Radial Piston Orientation







Summary

- Tested inline unit on existing digital pump/motor test stand
  - Results provided proof of concept for mechanical actuation
- Modeled and simulated inline unit
  - Validated modeling techniques
- Model and simulate radial unit
  - Use simulation to determine optimal parameters

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