EFFICIENT, COMPACT, AND SMOOTH VARIABLE PROPULSION MOTOR

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CCEFP Summit – Purdue 2019

June 5th, 2019

Project Team

- University of Minnesota
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  - Tom Chase, co-PI
  - Perry Li, co-PI
  - Mike Gust, Project Manager
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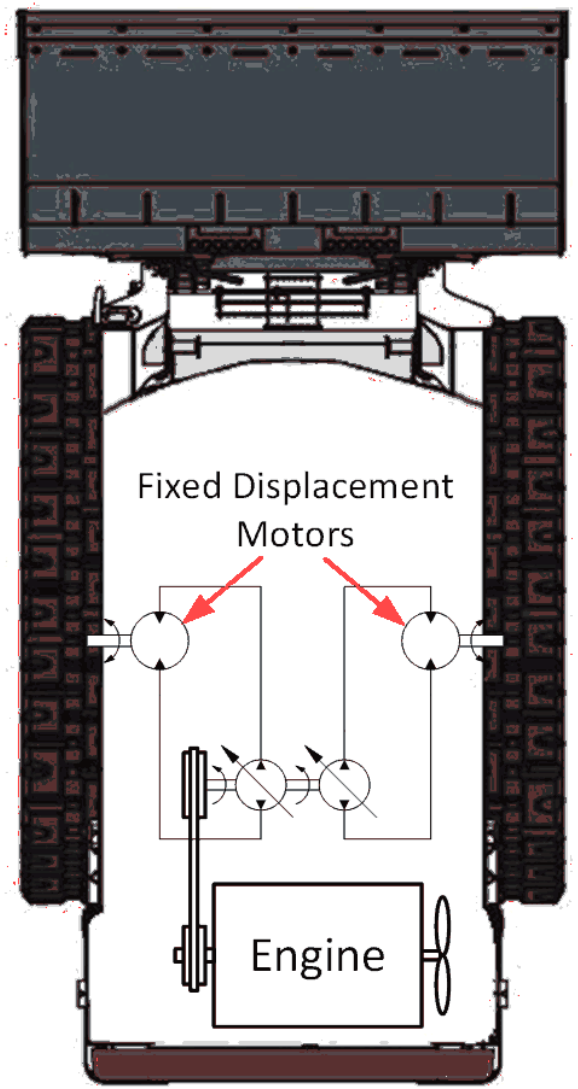
  - Justinus Hartoyo, GRA
  - John Voth, GRA
  - Shawn Wilhelm, Consultant
  - Marvin Flaschenriem, Consultant
- Milwaukee School of Engineering
  - Paul Michael, PI
  - Ninaad Gajghate, GRA
  - Jordan Saikia, GRA
- Bobcat Doosan
- Poclain Hydraulics

Project Overview

- Many off-highway vehicles use hydrostatic drives.
  - Variable displacement axial piston pump
  - Fixed displacement motor
- Pump displacement sets vehicle speed
  - Pump is inefficient at low displacements
- Variable displacement motor would decouple pump displacement and vehicle speed



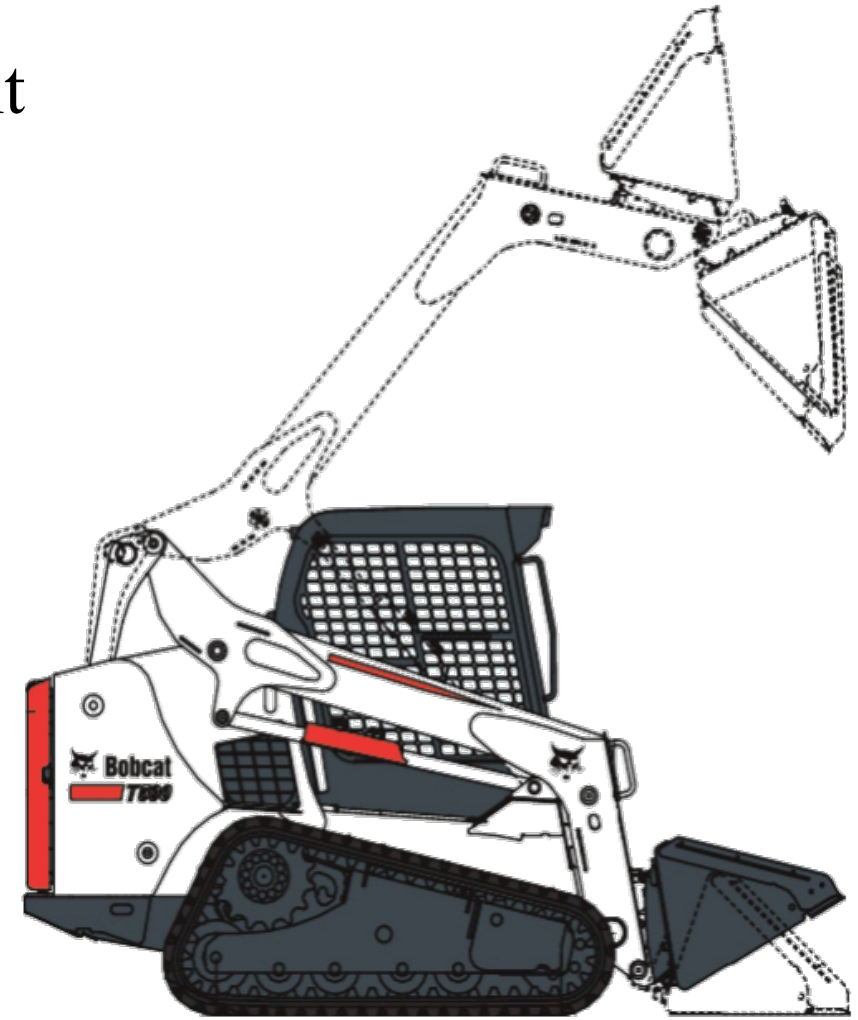
Value Propositions

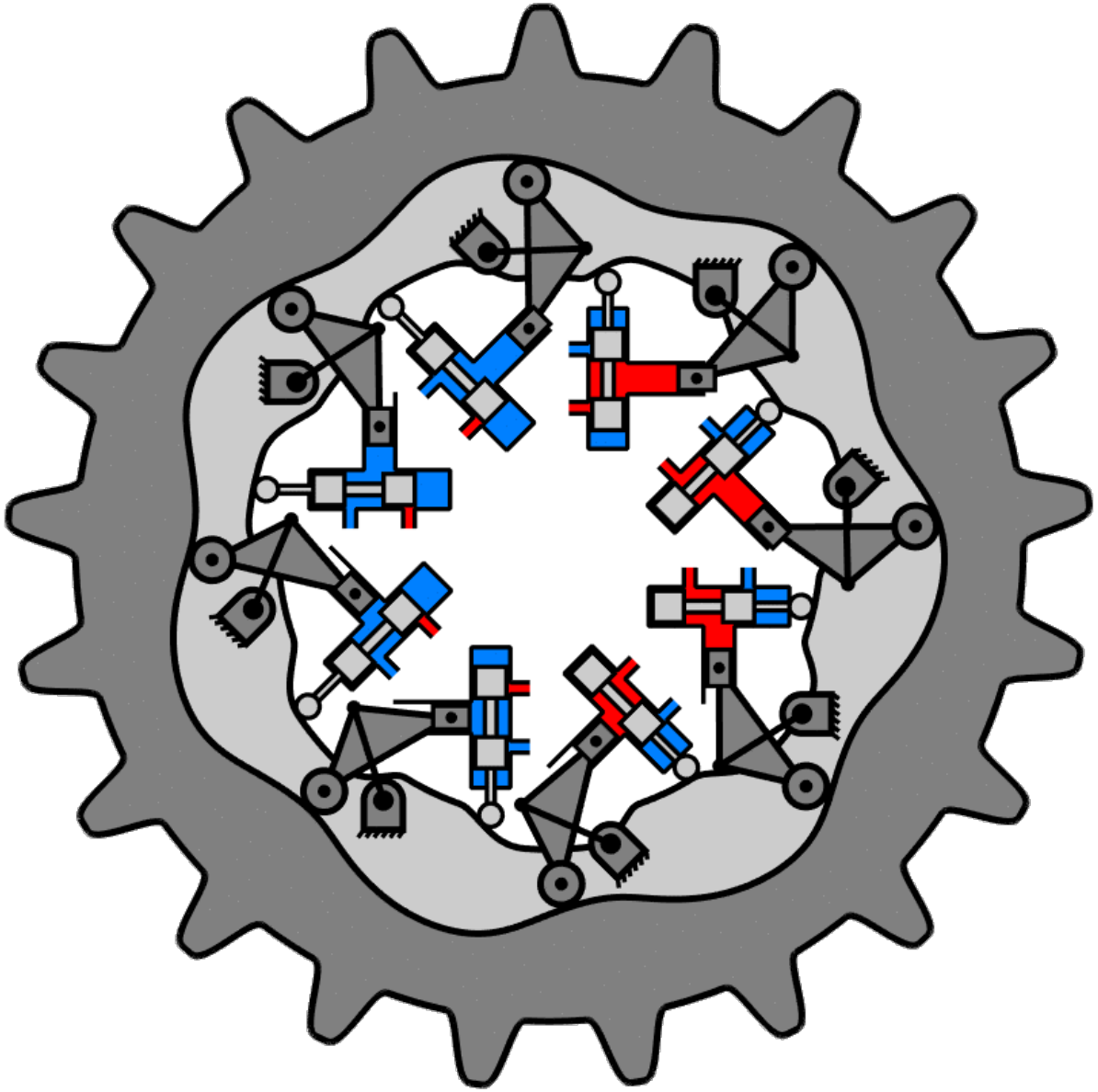
- **Motor Efficiency:** Saves fuel, increases power
- **Low Torque Ripple:** Improves control and productivity

- **Variable Displacement Motor:** Increases transport speed and higher system efficiency
- **High Displacement Motor:** Eliminates gearbox
- **Scalable Motor:** Applicable to wide variety of off-highway vehicles

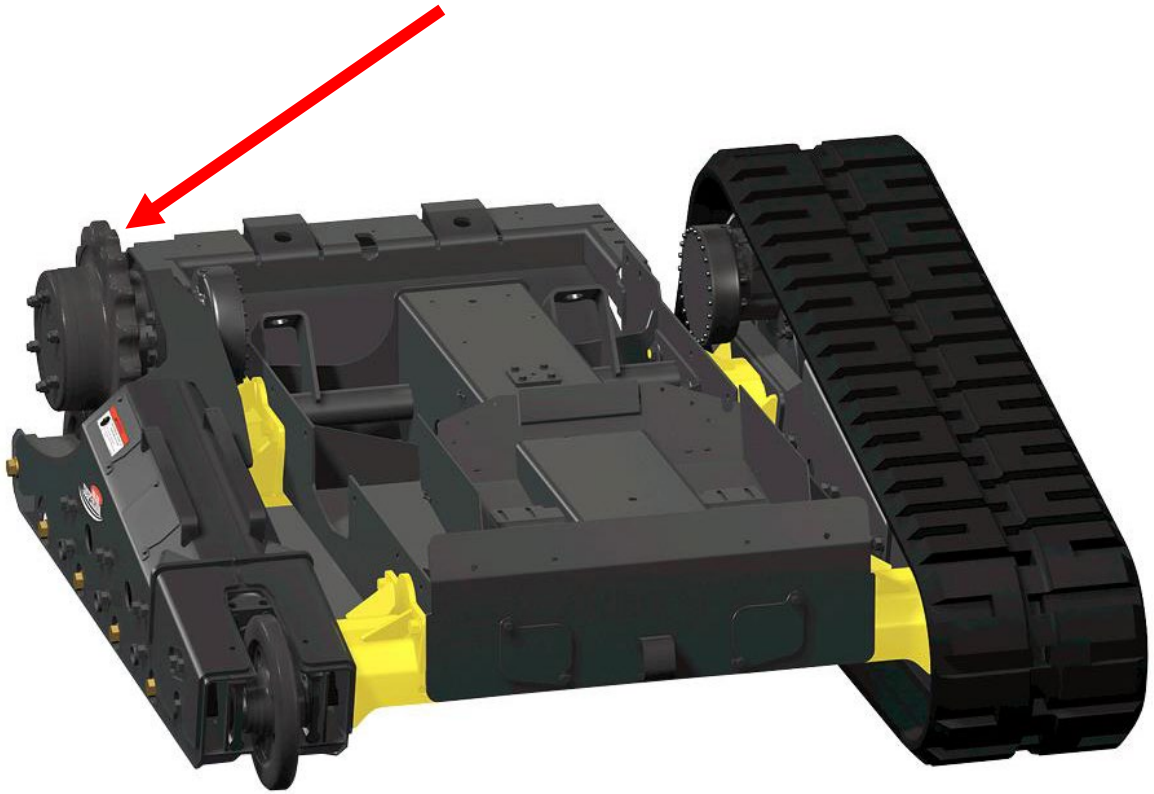
Project Objectives

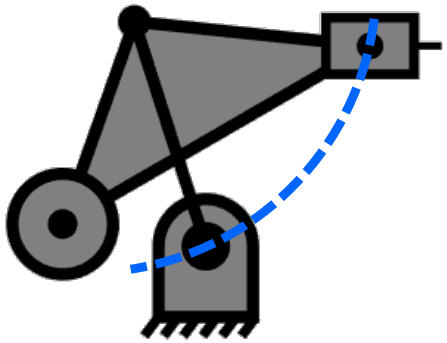
- Efficiency >90% above 50% displacement
- Torque ripple <5% of the mean torque
- Reduce vehicle fuel consumption by 30%
- Power density >5 kW/kg
- Cost <$4/kW

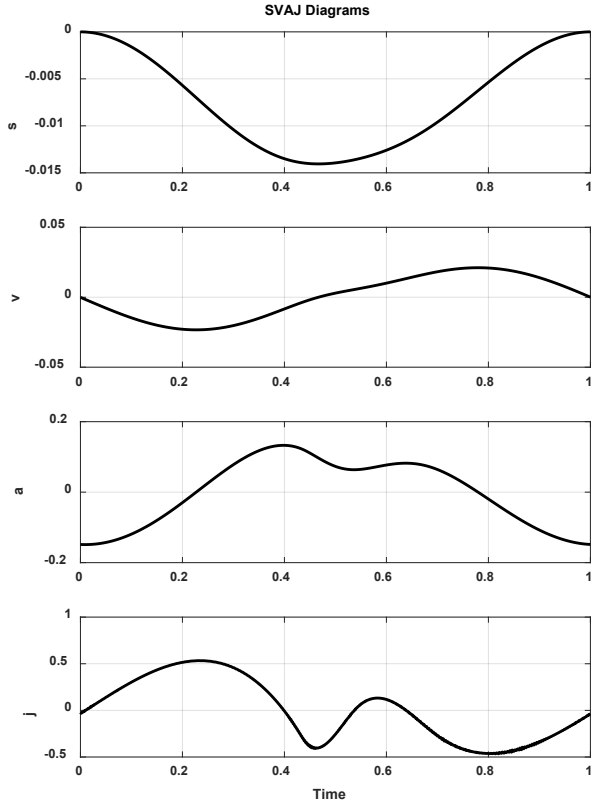


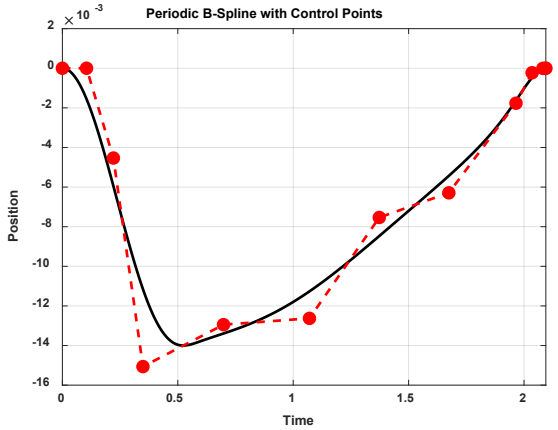


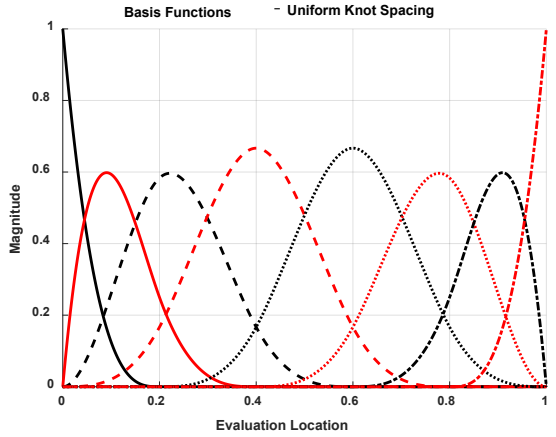
Low Speed High Torque (LSHT) direct drive hydraulic motor with track drive sprocket

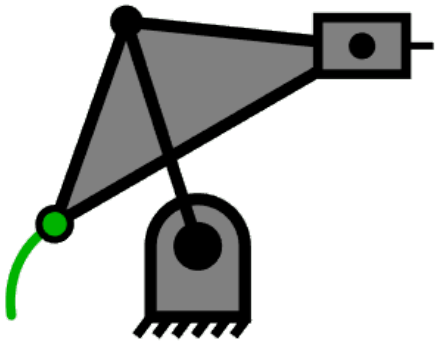


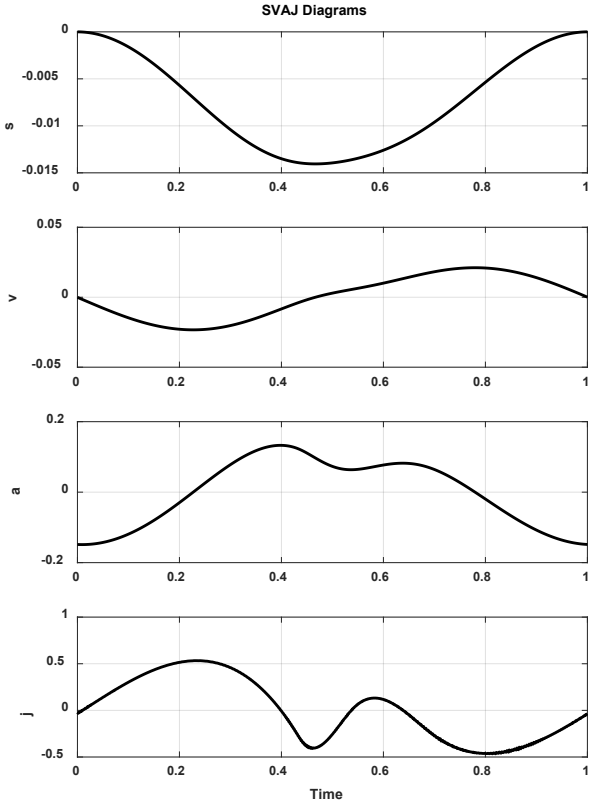



SVAJ Diagrams
s
v
a
j
Time


Periodic B-Spline with Control Points
Position
Time


Basis Functions
Uniform Knot Spacing
Magnitude
Evaluation Location

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s
v
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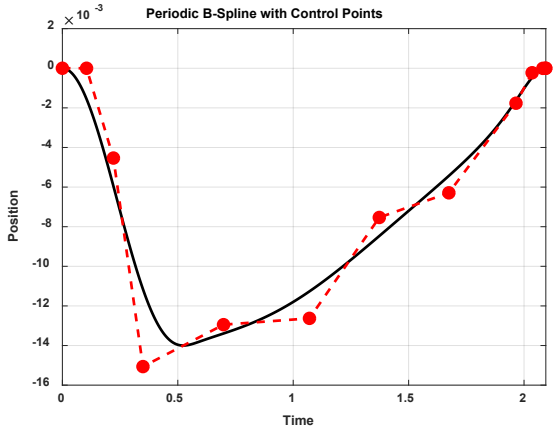
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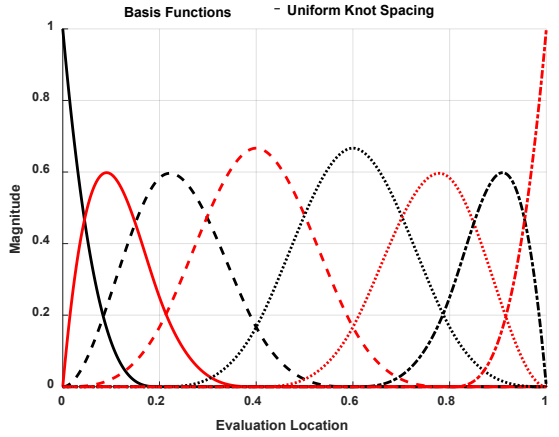
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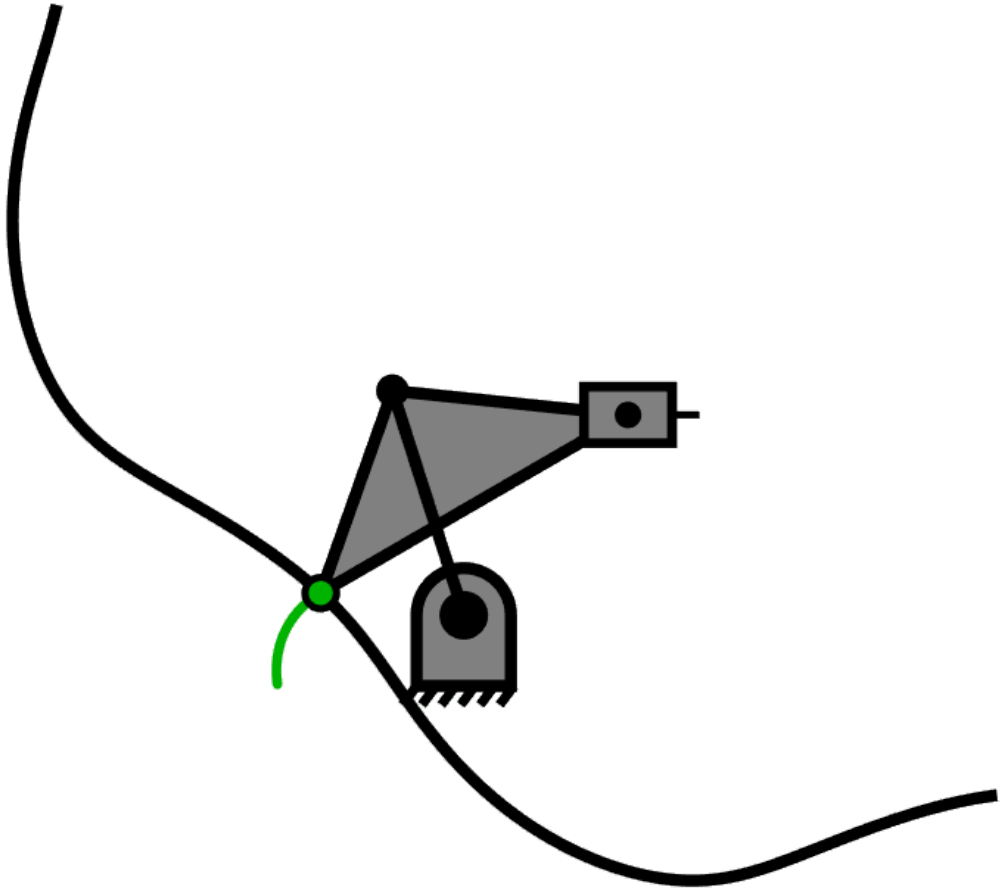


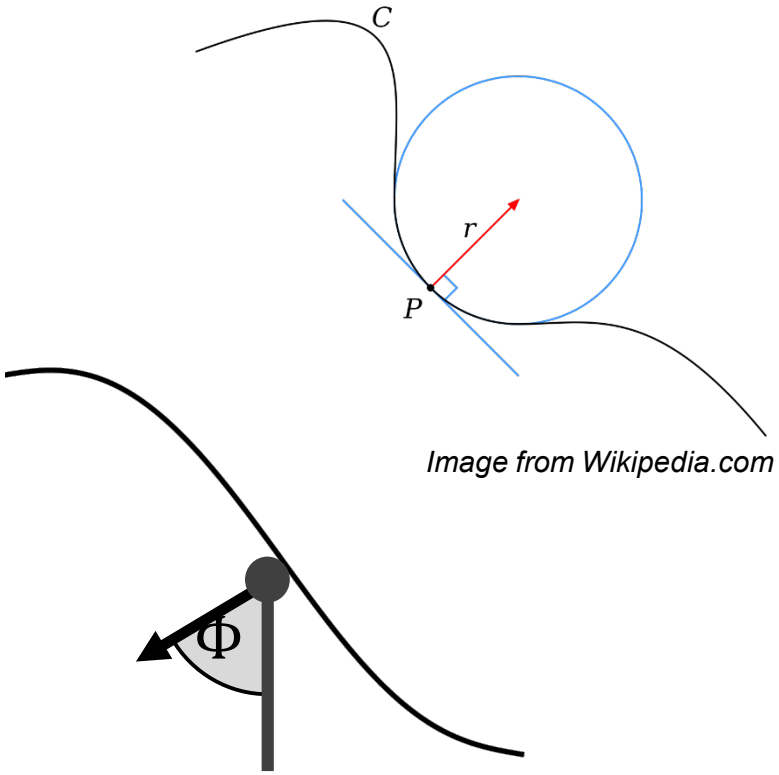
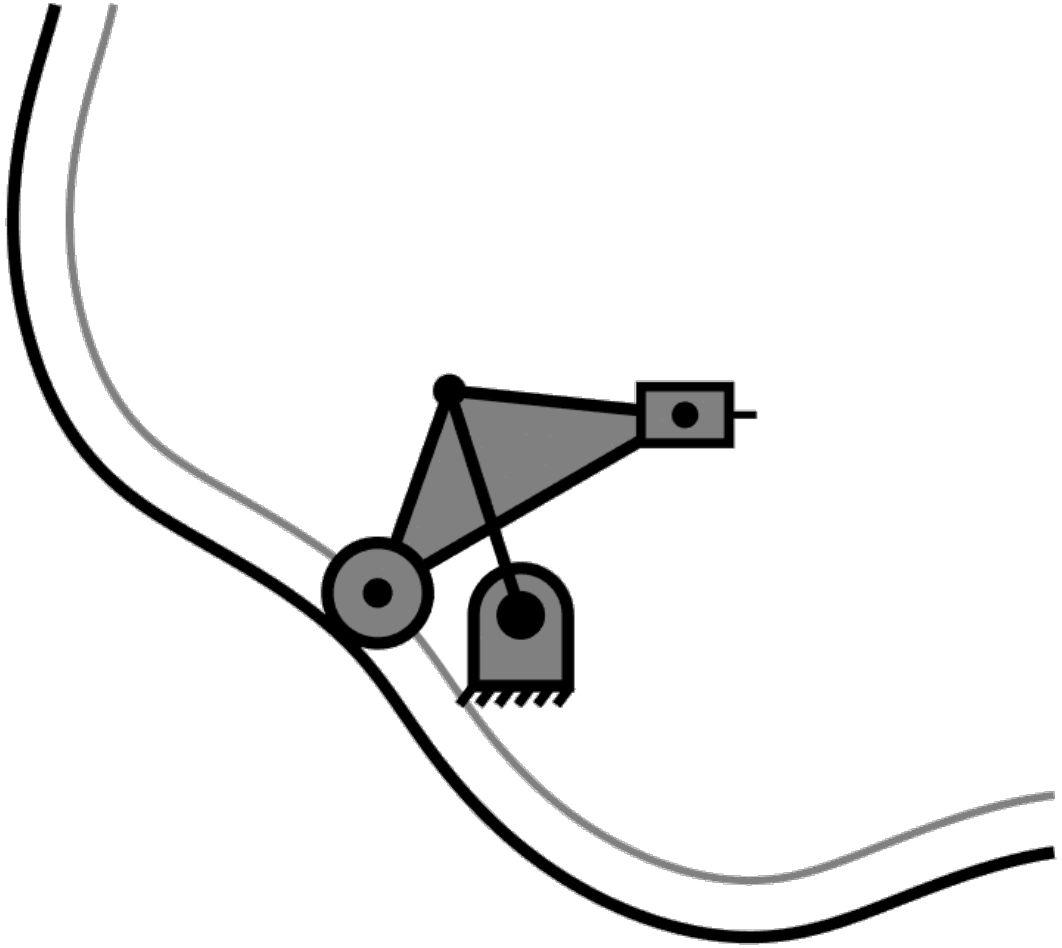
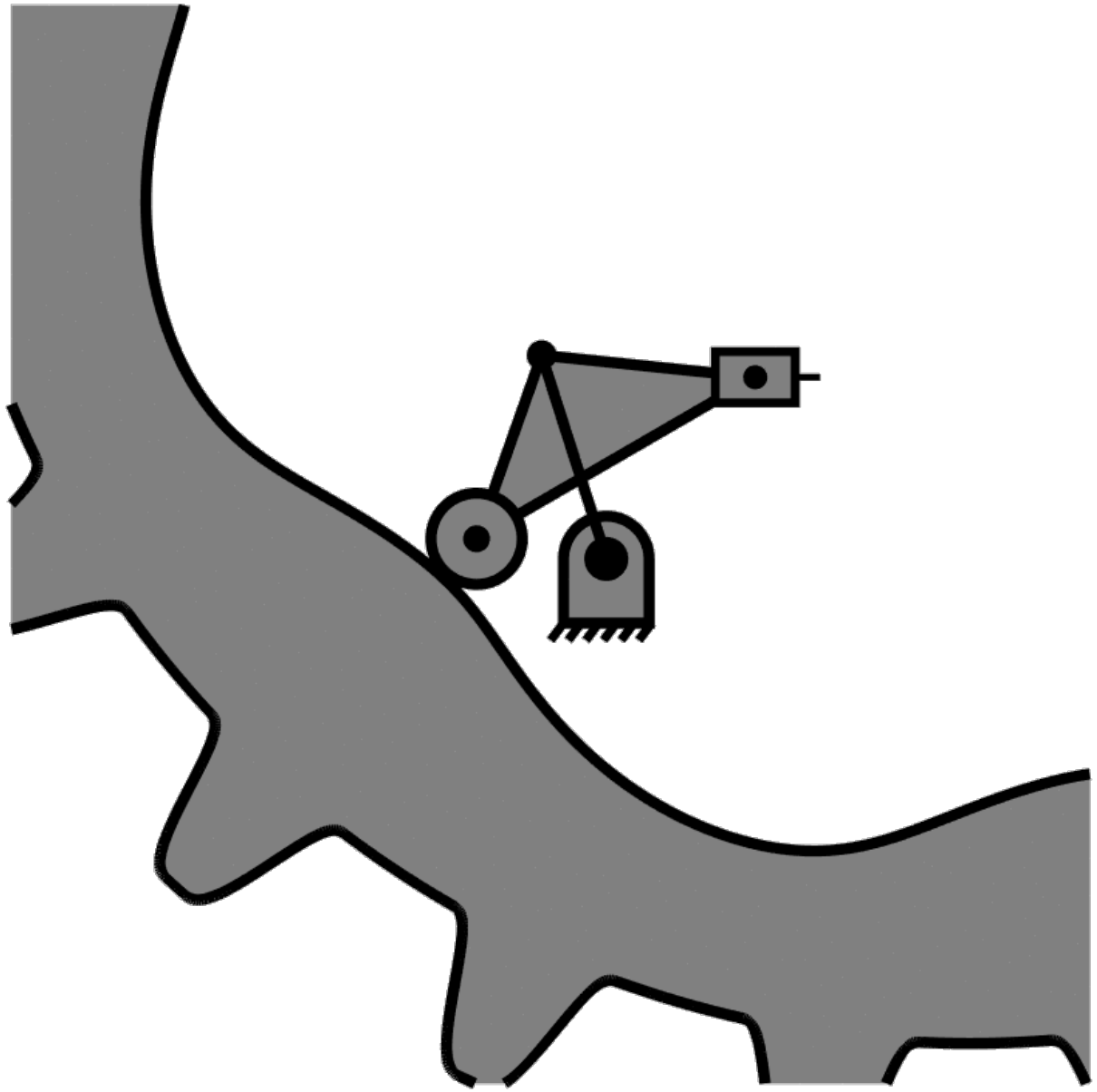
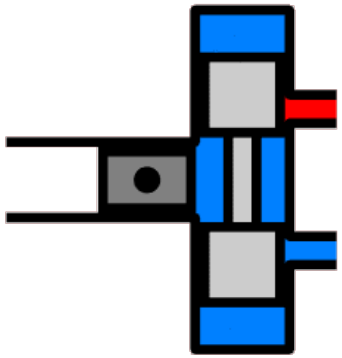
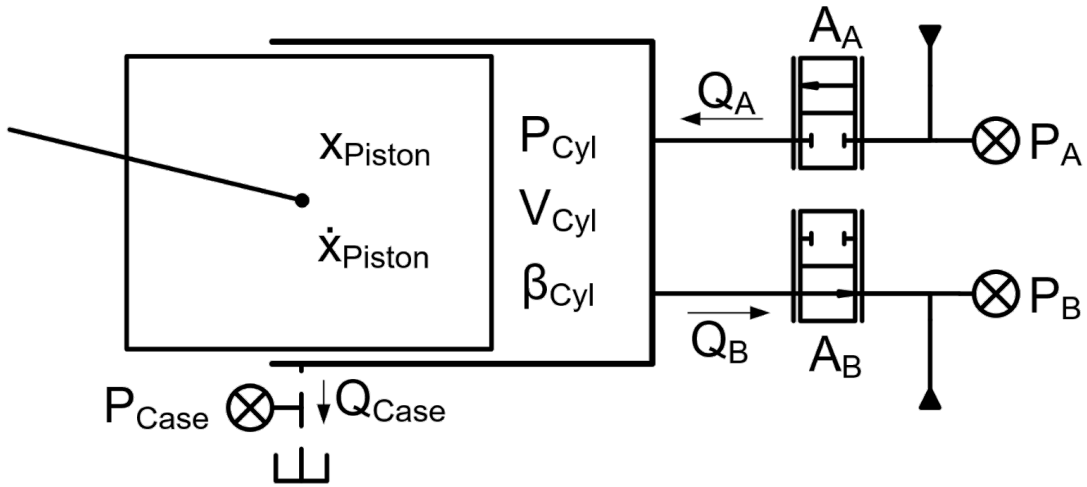


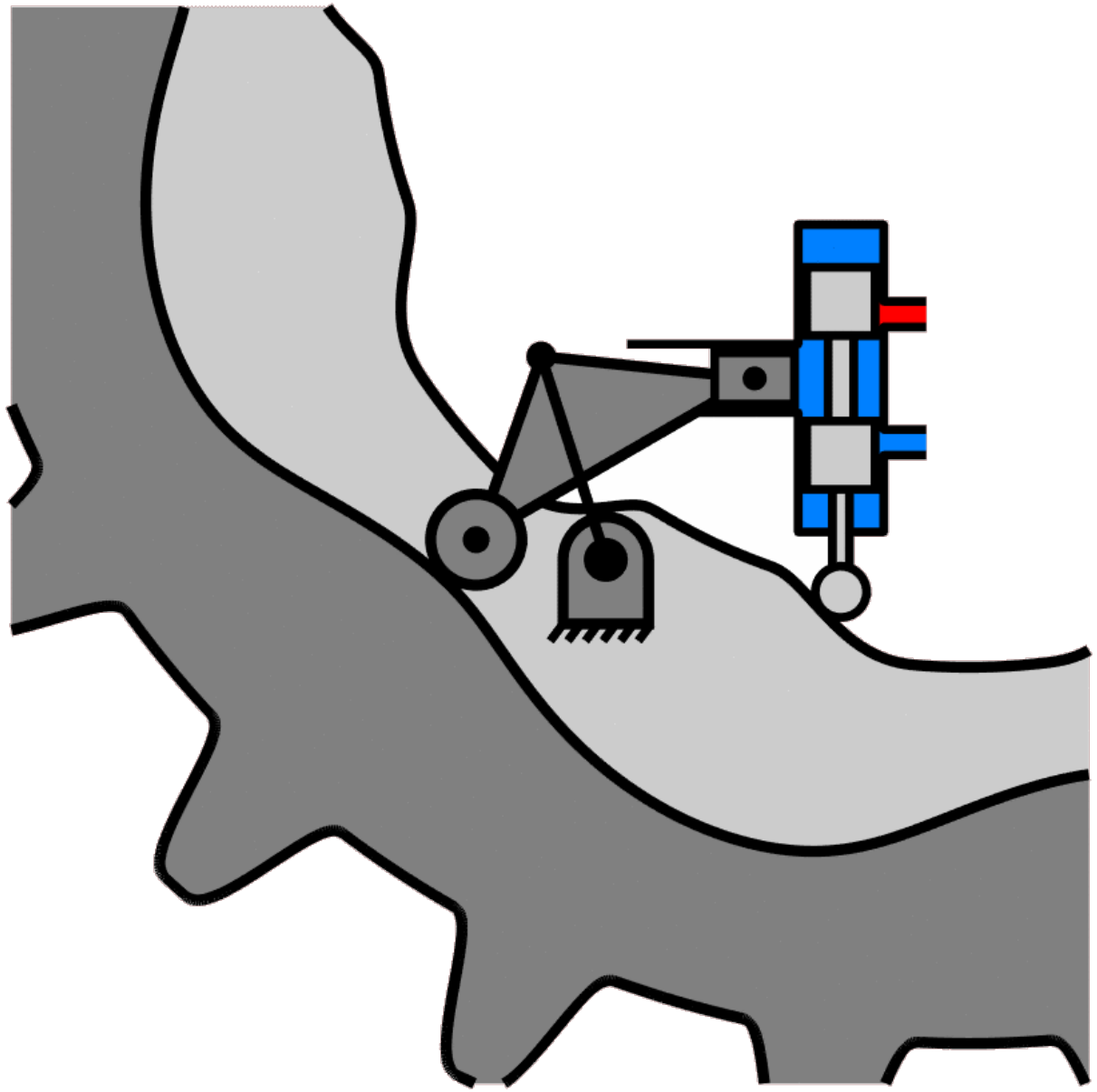
Image from Wikipedia.com

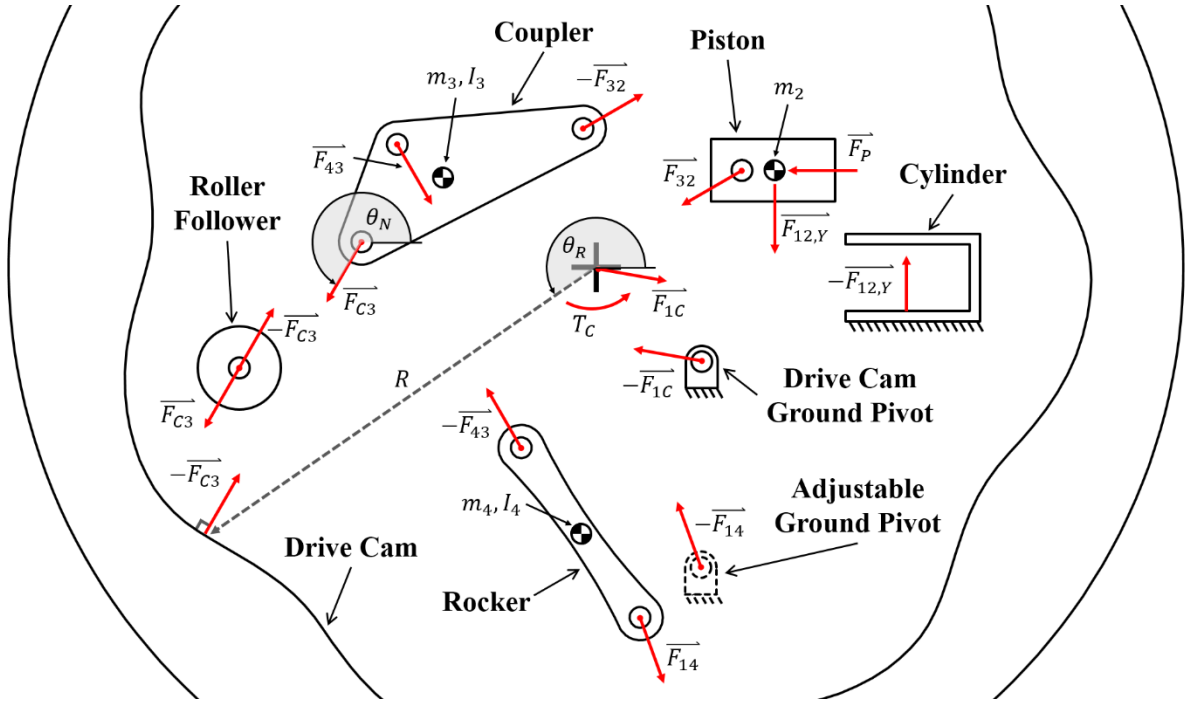


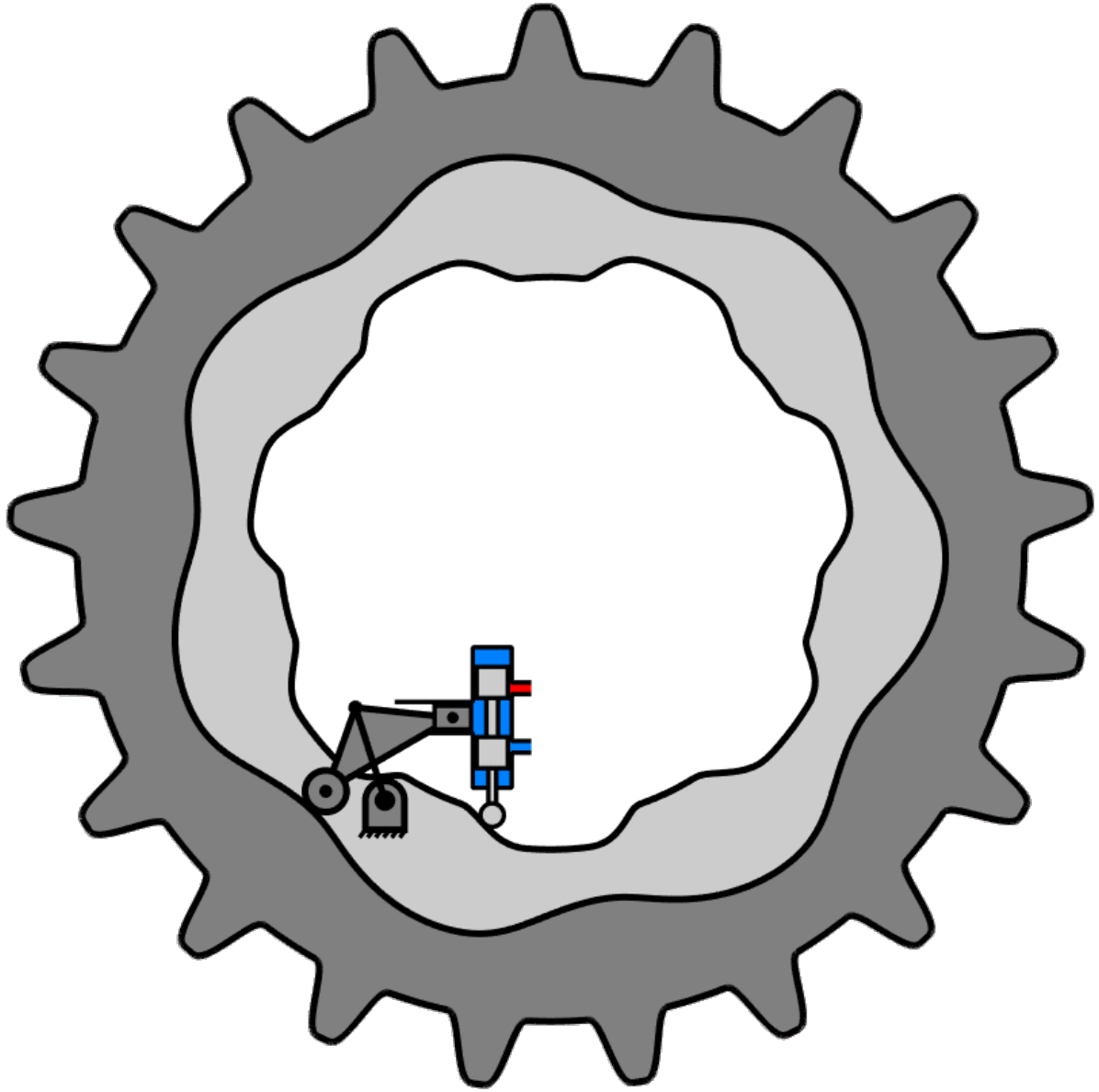


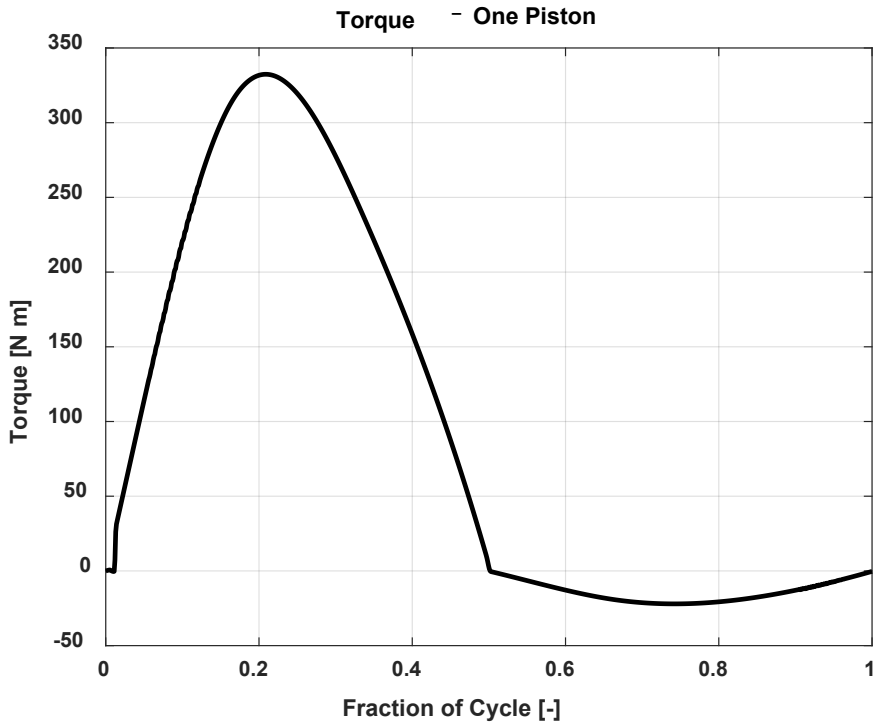


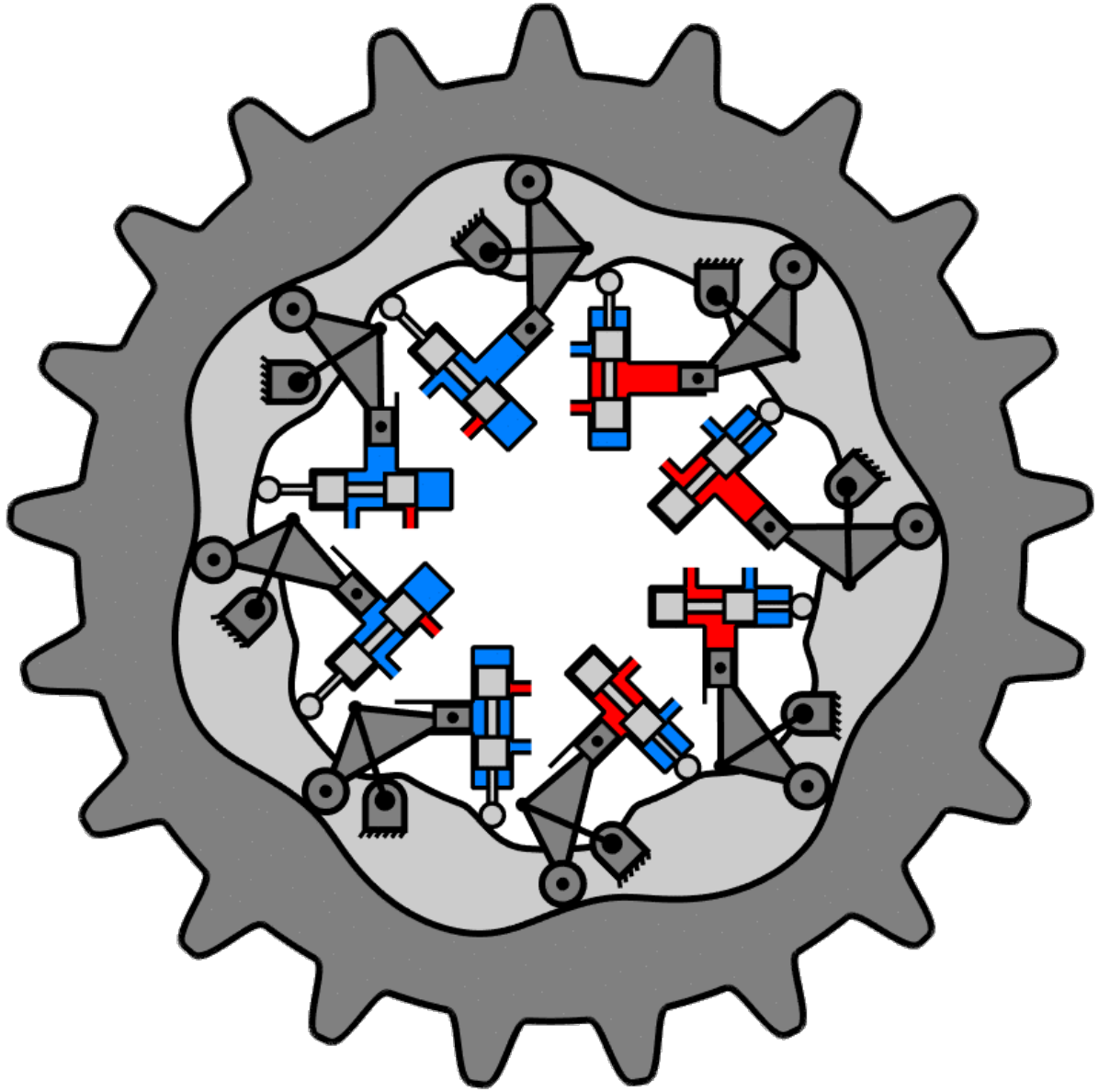

A_A
Q_A
P_A
x_{Piston}
$\dot{x}_{Piston}$
P_{Cyl}
V_{Cyl}
β_{Cyl}
Q_B
P_B
A_B
P_{Case}
Q_{Case}

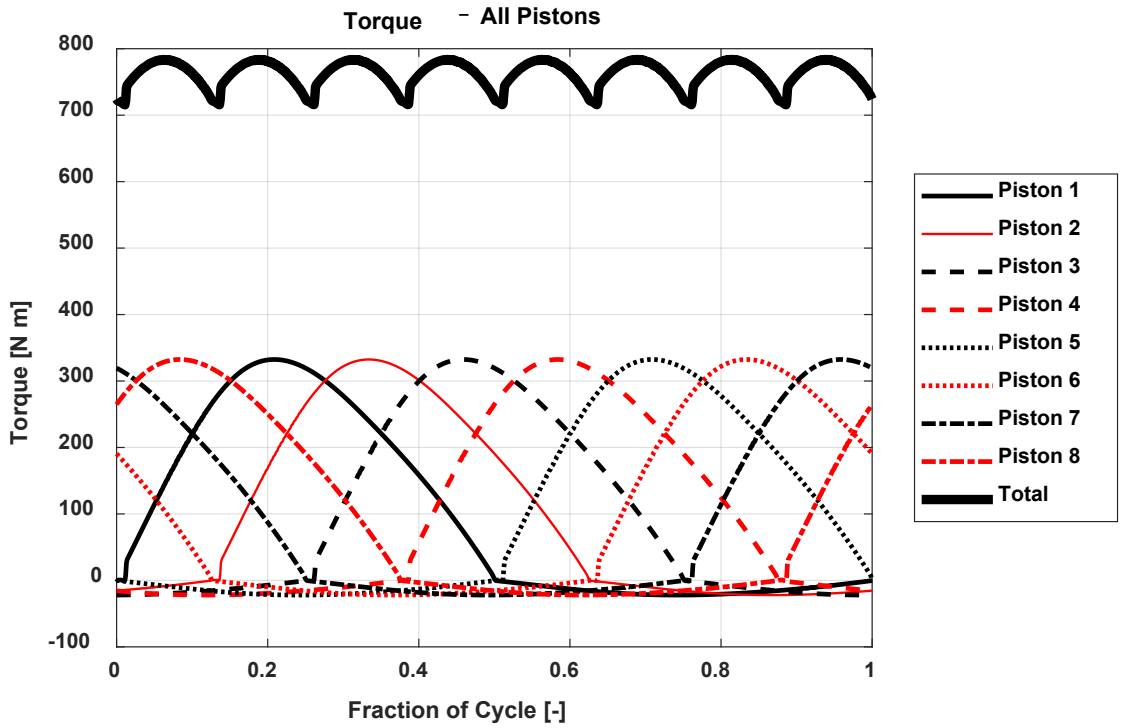



Coupler
Piston
Cylinder
Roller Follower
Drive Cam
Drive Cam Ground Pivot
Adjustable Ground Pivot
Rocker
m_3, I_3
m_2
m_4, I_4
$-\overrightarrow{F_{32}}$
$\overrightarrow{F_{43}}$
$\overrightarrow{F_P}$
$\overrightarrow{F_{32}}$
$\overrightarrow{F_{12,Y}}$
$-\overrightarrow{F_{12,Y}}$
θ_N
θ_R
$\overrightarrow{F_{C3}}$
$-\overrightarrow{F_{C3}}$
T_C
$\overrightarrow{F_{1C}}$
$-\overrightarrow{F_{1C}}$
R
$-\overrightarrow{F_{43}}$
$-\overrightarrow{F_{14}}$
$\overrightarrow{F_{14}}$



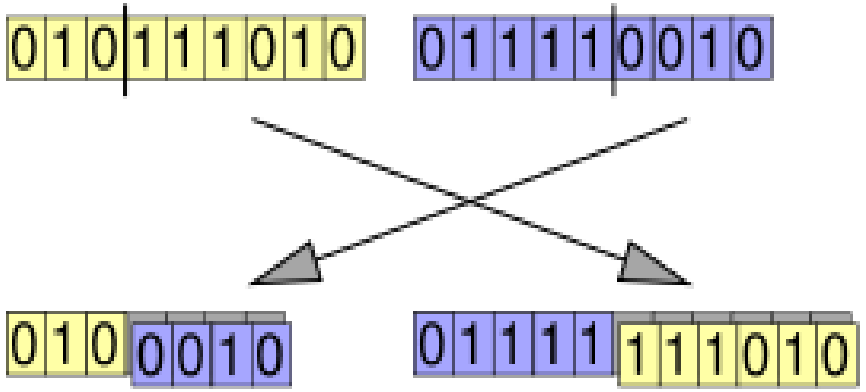

Torque - One Piston
Torque [N m]
350
300
250
200
150
100
50
0
-50
0
0.2
0.4
0.6
0.8
1
Fraction of Cycle [-]




Torque – All Pistons
800
700
600
500
400
300
200
100
0
-100
Torque [N m]
0
0.2
0.4
0.6
0.8
1
Fraction of Cycle [-]
Piston 1
Piston 2
Piston 3
Piston 4
Piston 5
Piston 6
Piston 7
Piston 8
Total

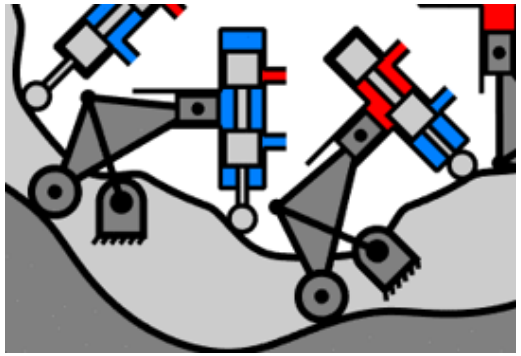
Model Optimization

- 10 independent variables
  - Piston trajectory
  - Linkage geometry
  - Linkage location
- 3 objectives
- Multiple solutions that meet objectives
- Multi Objective Genetic Algorithm



Objective Functions

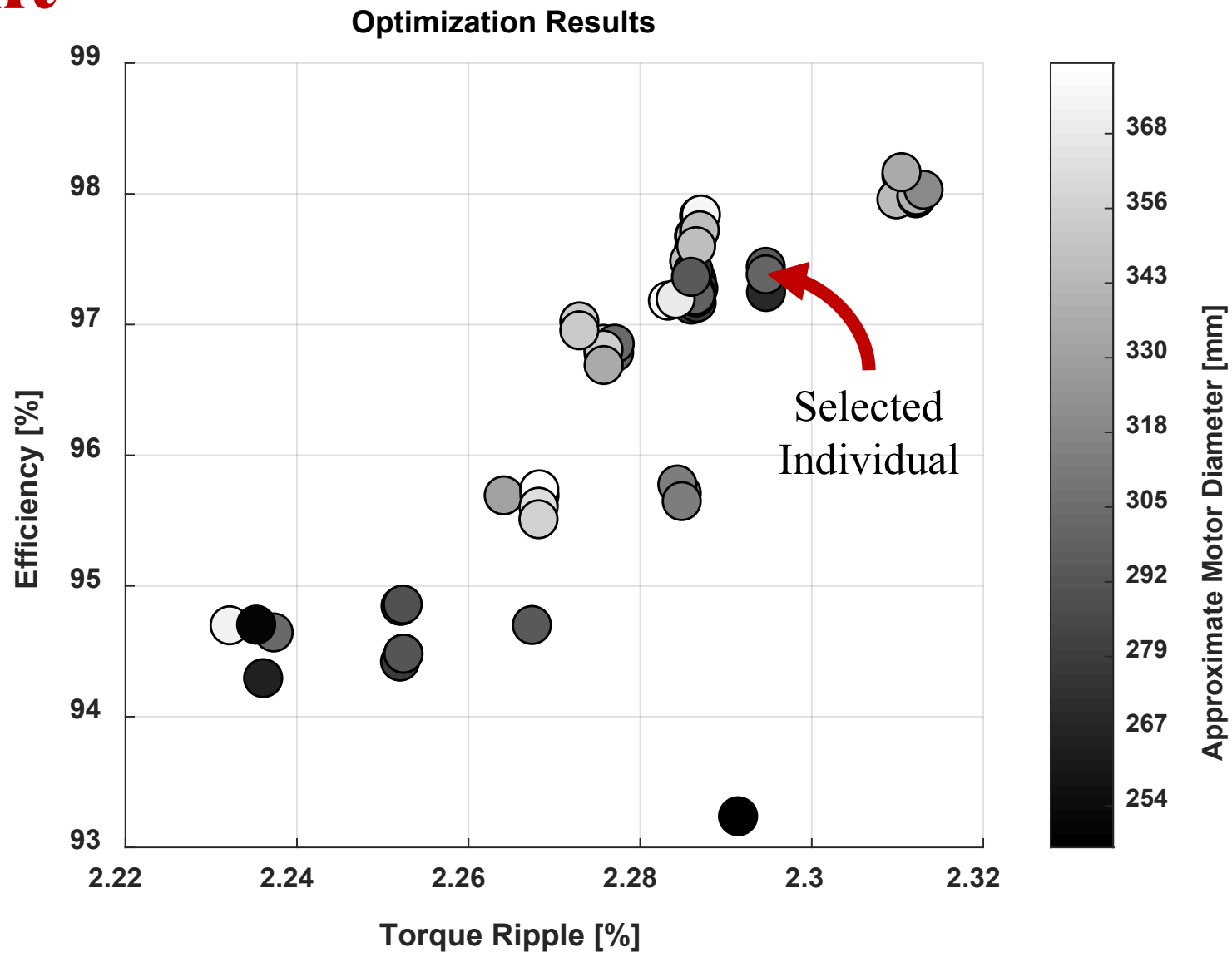
- Efficiency
  - Throttling losses
  - Frictional losses
- Torque Ripple
- Size
  - Diameter of outermost point of motor



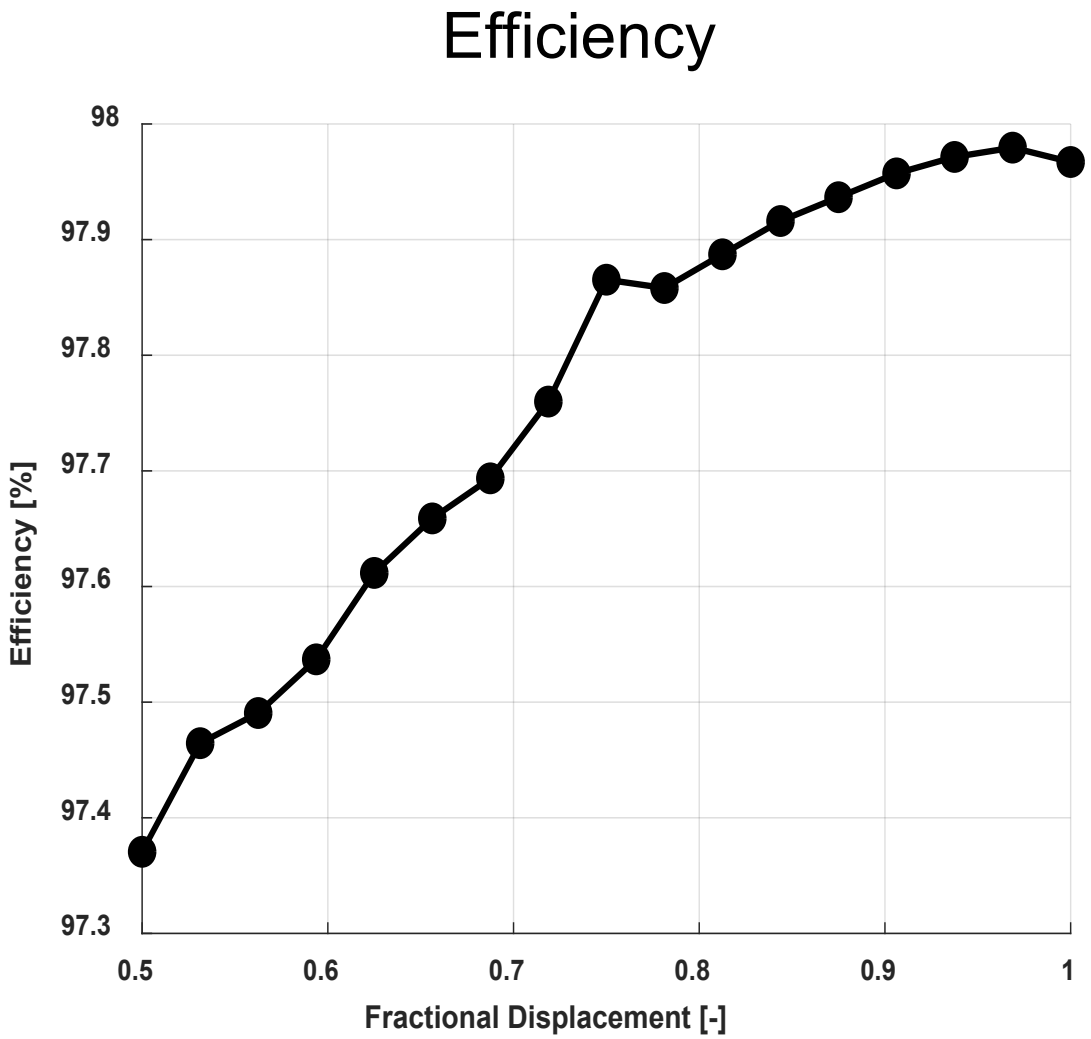
Penalty Functions

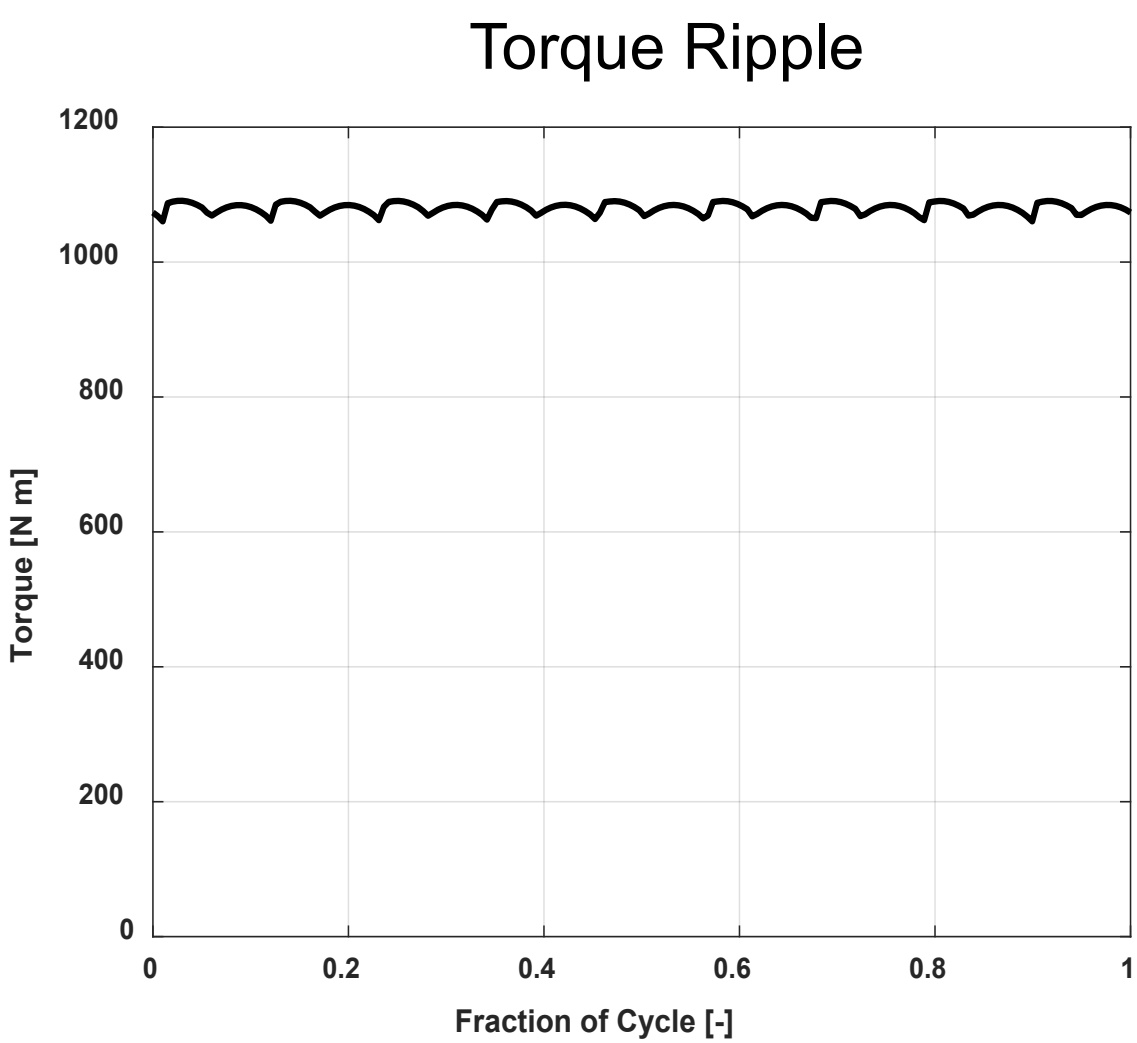
- Efficiency
  - Cavitation
  - Excessive joint forces
- Size
  - Interference between
    - Bearings
    - Linkage modules
    - Adjustable ground pivots and the cam
  - Radius of roller follower too large

Pareto Front



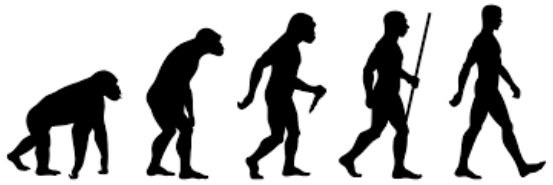
Individual's Results

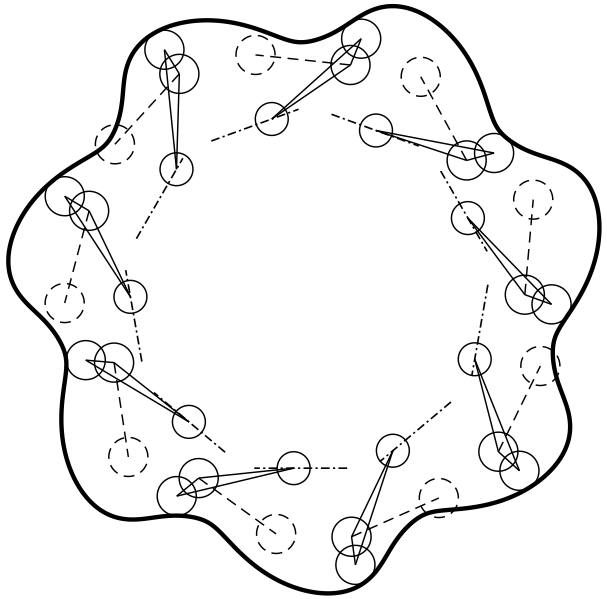




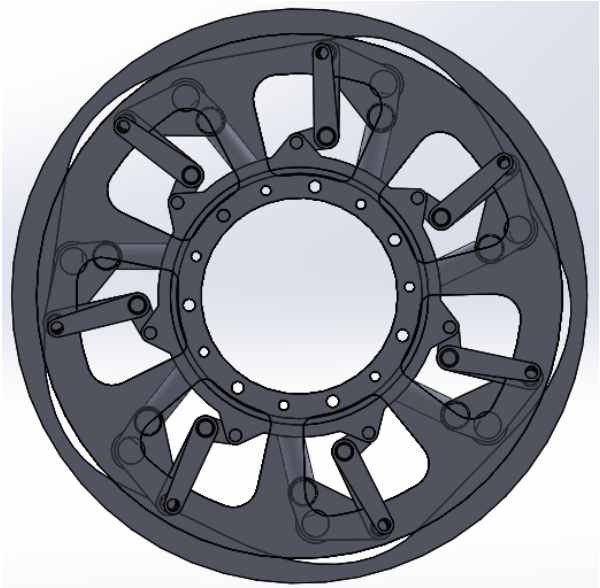
Future Work

We are here





- ✓ Year One
  - Modeling
  - Early optimizations
- ❑ Year Two – Single Cylinder Prototype
  - More optimizations
  - Detailed mechanical design (CAD)
  - Experimental model validation
- ❑ Year Three – Full Prototype
  - Finalize scaled multi-cylinder design
  - Test multi-cylinder prototype



Acknowledgement

- This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Vehicle Technologies Office Award Number DE-EE0008335

THANK YOU

ANY QUESTIONS?

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