

# EFFICIENT, COMPACT, AND SMOOTH VARIABLE PROPULSION MOTOR

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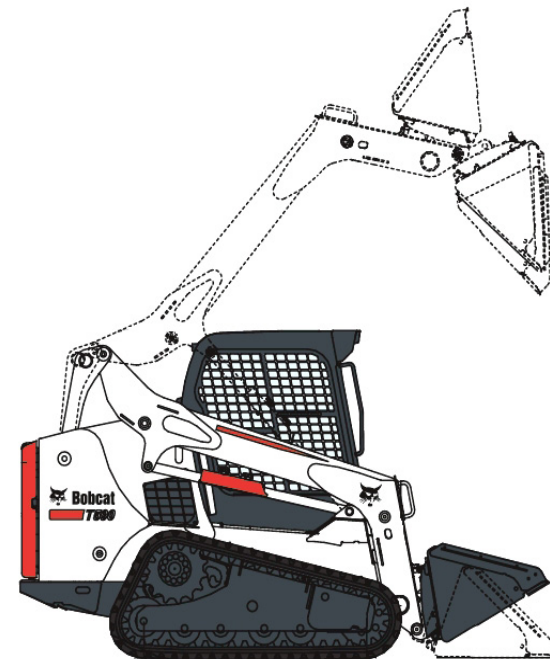


# Project Overview

- Develop variable displacement linkage motor (VDLM) for propulsion of off-highway vehicles
- 36 month timeline

## Objectives:

- Efficiency  $>90\%$  above 15% displacement
- Torque ripple  $<5\%$  of the mean torque
- Reduce fuel consumption 30%
- Power density  $>5$  kW/kg
- Cost  $<\$4/\text{kW}$



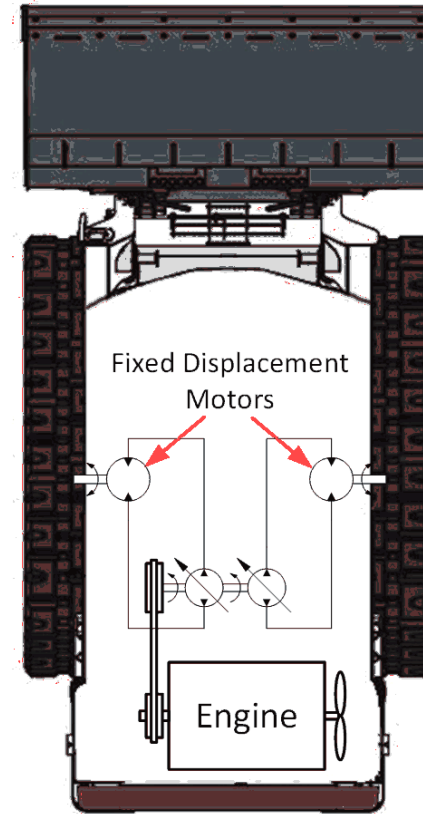
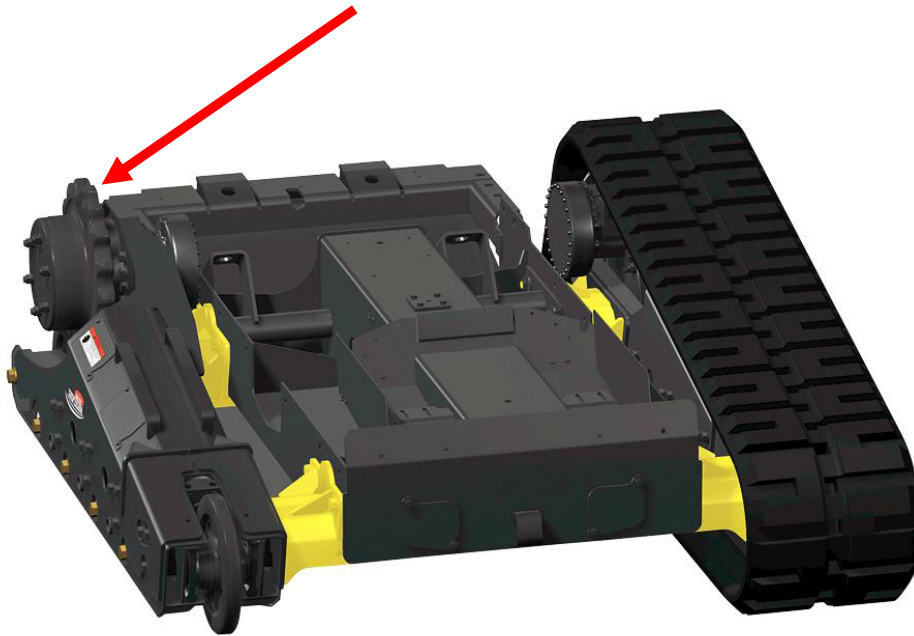
# Project Team

- University of Minnesota
  - Jim Van de Ven, PI
  - Tom Chase, co-PI
  - Perry Li, co-PI
  - Mike Gust, Project Manager
  - Grey Boyce-Erickson, GRA
  - Nate Fulbright, GRA
  - Justinus Hartoyo, GRA
  - John Voth, GRA
  - Shawn Wilhelm, Consultant
- Milwaukee School of Engineering
  - Paul Michael, PI
  - Ninaad Gajghate, GRA
  - Pawan Panwar, GRA
  - Jordan Saikia, GRA
- Eaton Corporation
- Bobcat Doosan



# Track Drive Hydraulic Motor

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



# VLDM Value Propositions

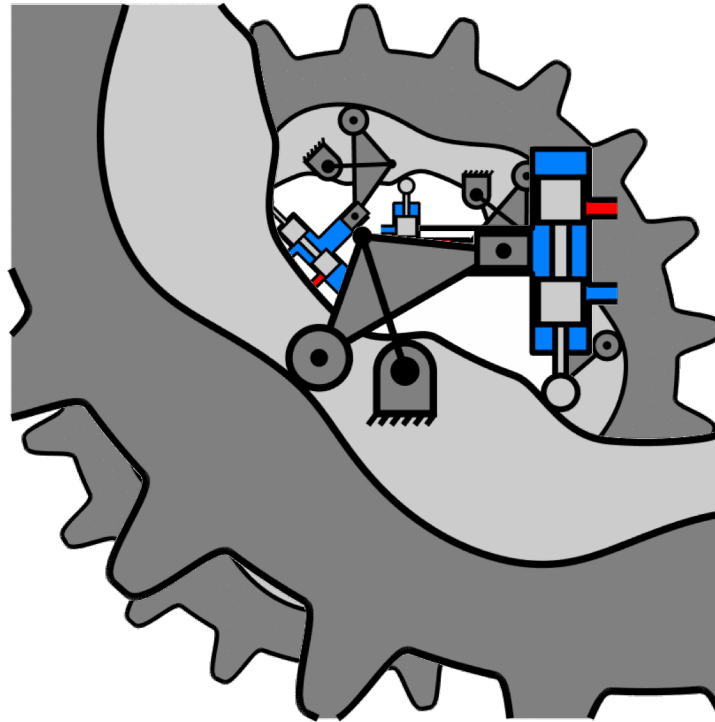


- **Motor Efficiency:** Saves fuel, increases power
- **Low Torque Ripple:** Improves control and productivity

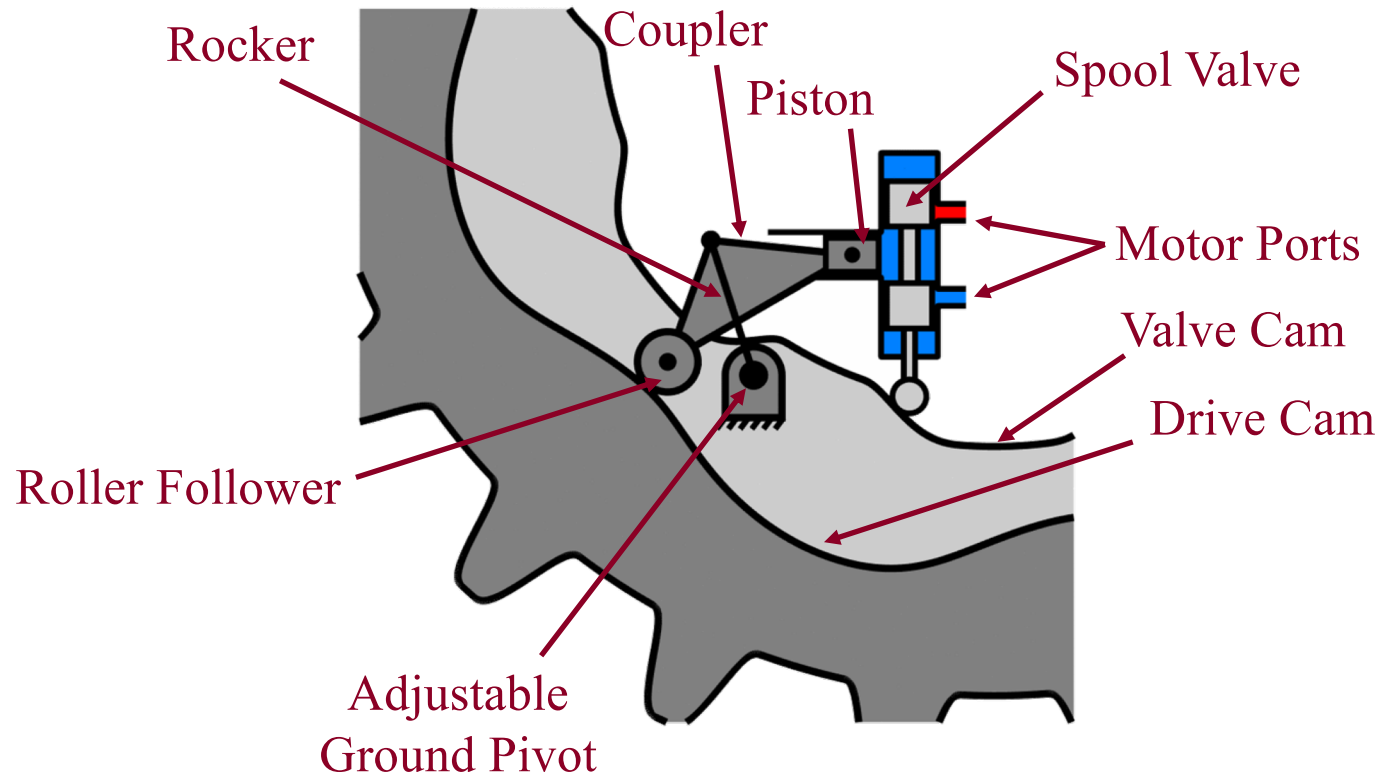
- **Variable Displacement Motor:** Increases transport speed and higher system efficiency
- **High Displacement Motor:** eliminates gearbox
- **Scalable Motor:** Applicable to wide variety of off-highway vehicles



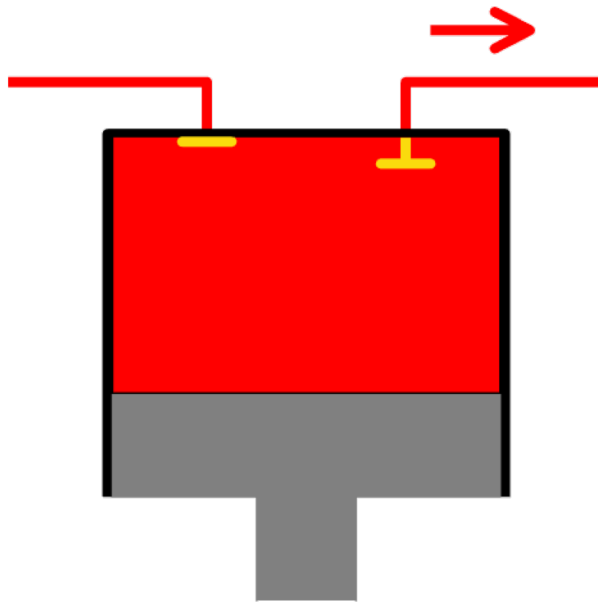
# How it Works: VDLM



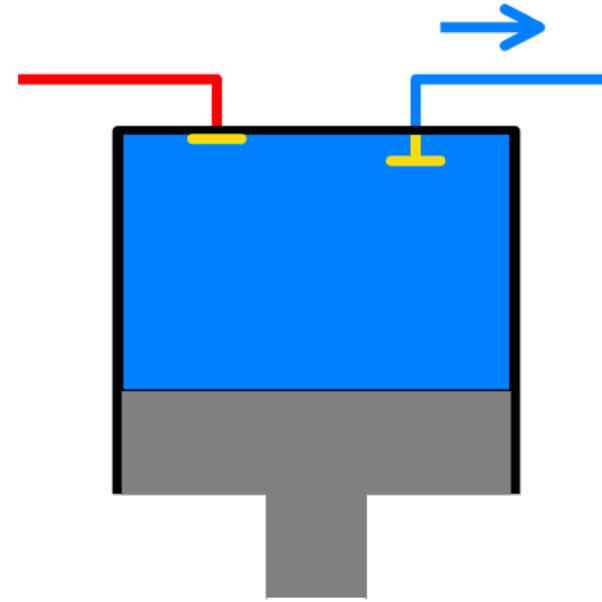
# How it Works: VDLM



# Importance of Valve Timing



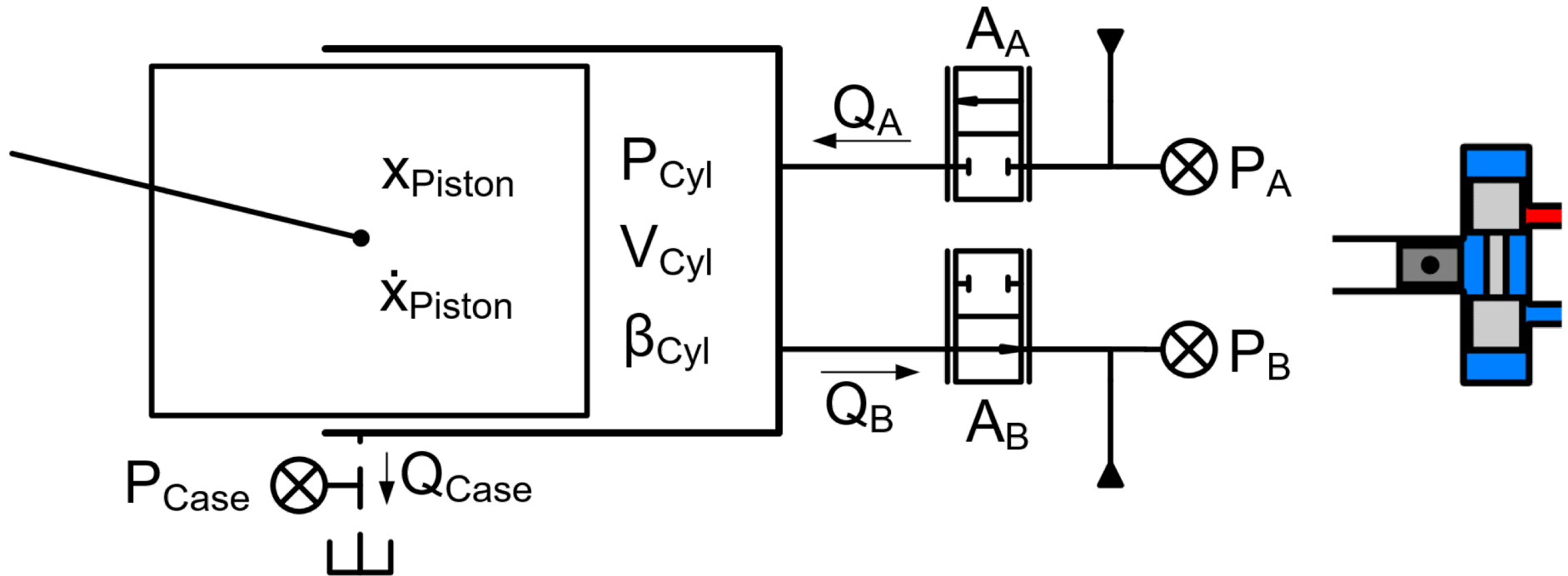
Maximum Power



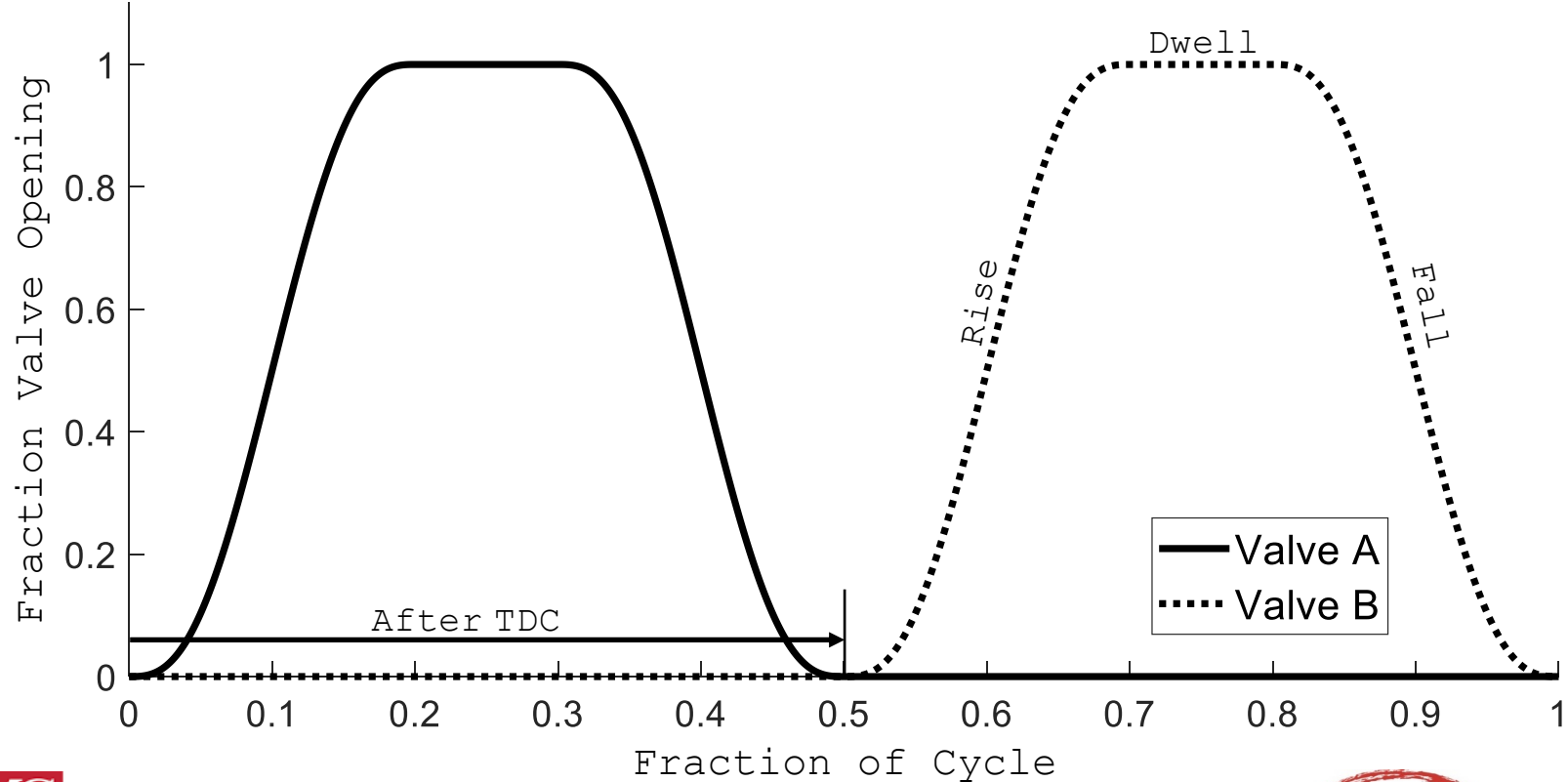
Maximum Efficiency  
(Pre-Compression &  
Decompression)



# Cylinder Model



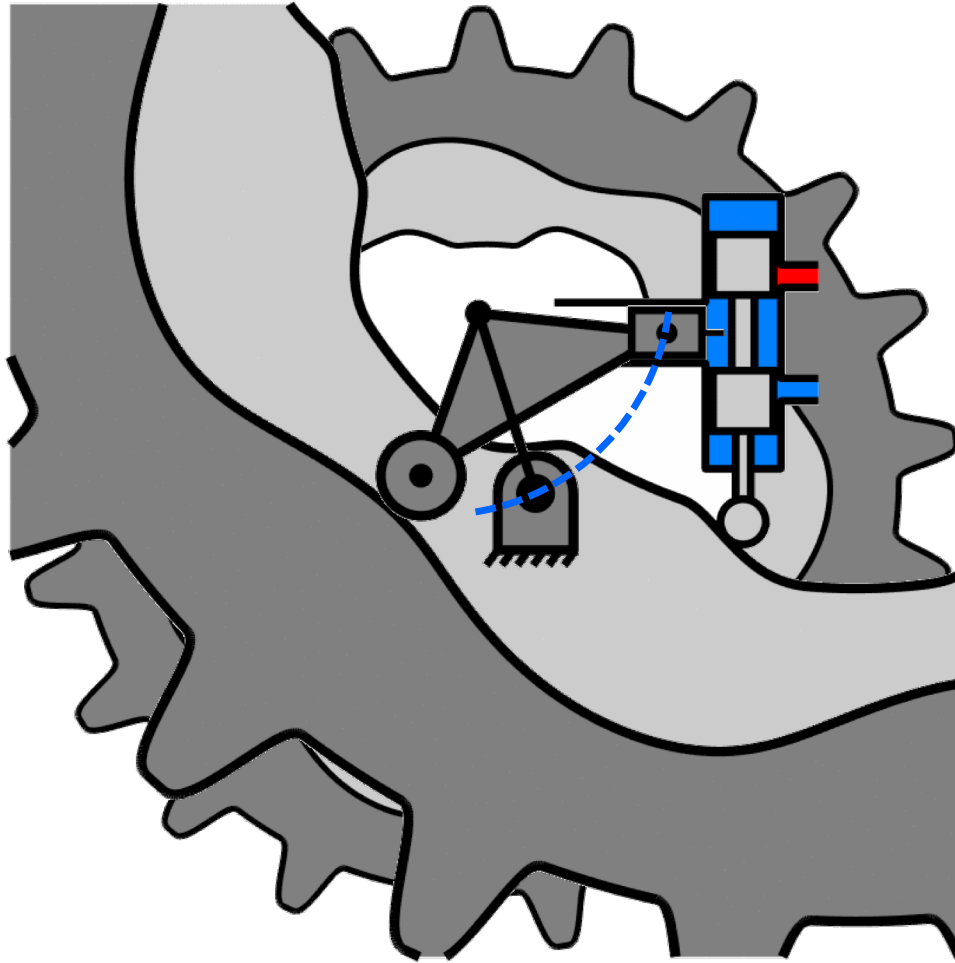
# Valve Timing



# Model Based Design Studies

- Is fixed valve timing sufficient, or is variable valve timing necessary?
- Which is preferred, cam or hydraulic driven valve actuation?
- Spool or poppet valve?





# Generating Cam

- Method 1 (conventional)
  - Create cam with desired properties
  - Analyze motion of linkage driven by cam
  - Observe piston trajectory
- Method 2 (our method)
  - Create piston trajectory
  - Analyze motion of linkage
  - Calculate cam that moves linkage as desired



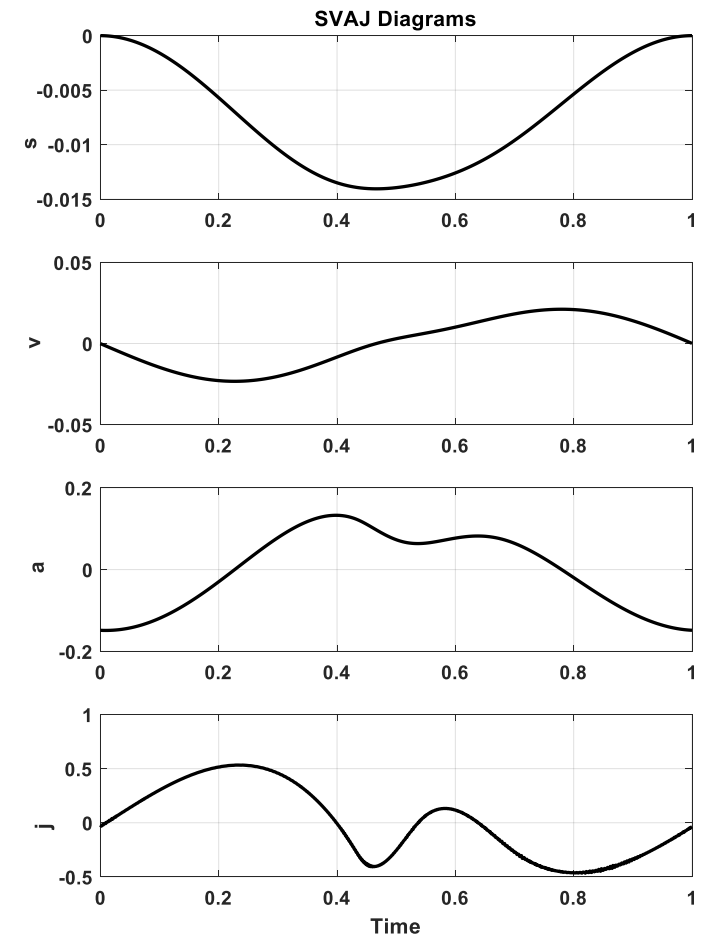
# Piston Trajectory – Generation

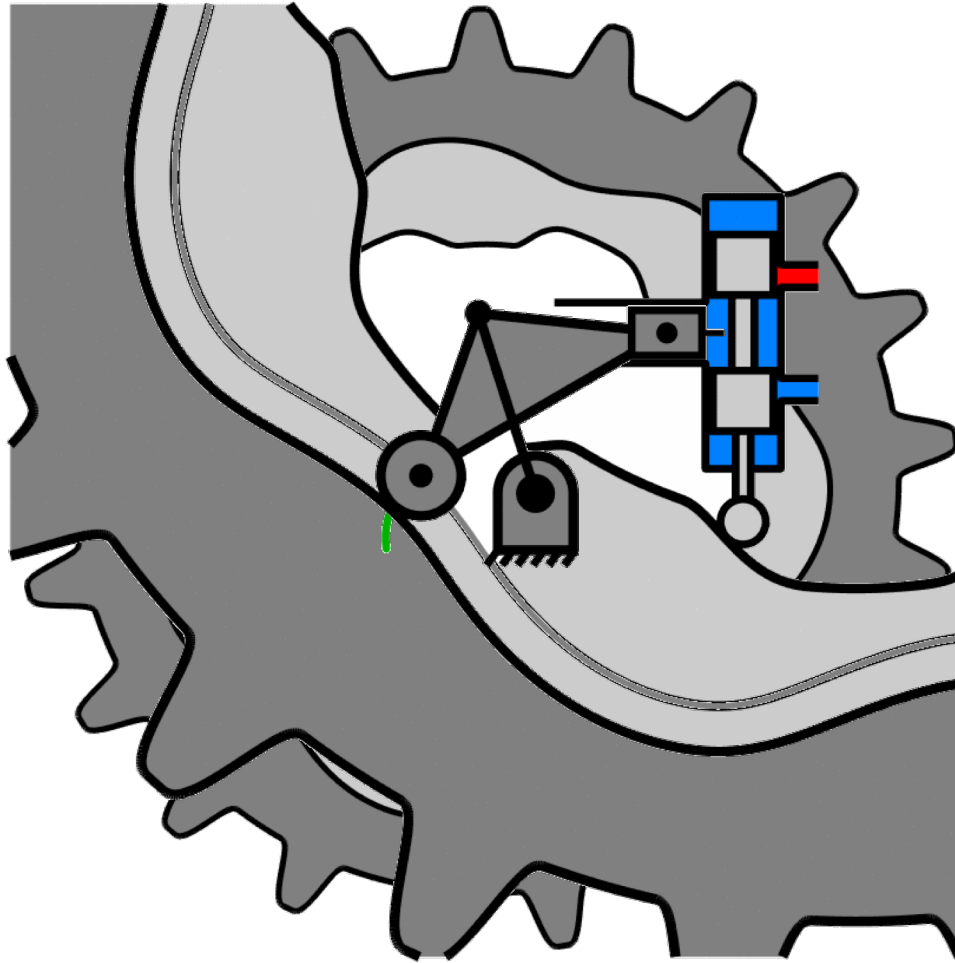
## Importance

- Controls torque ripple

## Generation

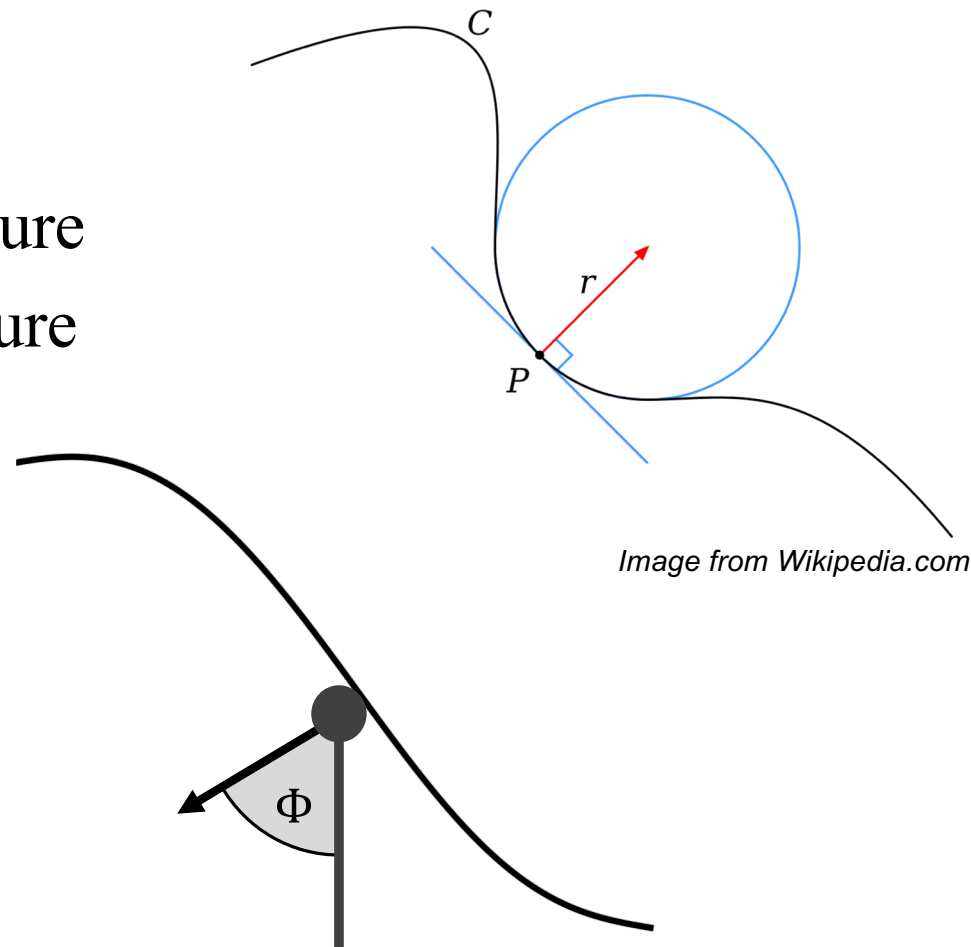
- Periodic B-spline
- Continuous through (at least) acceleration





# Cam Analysis

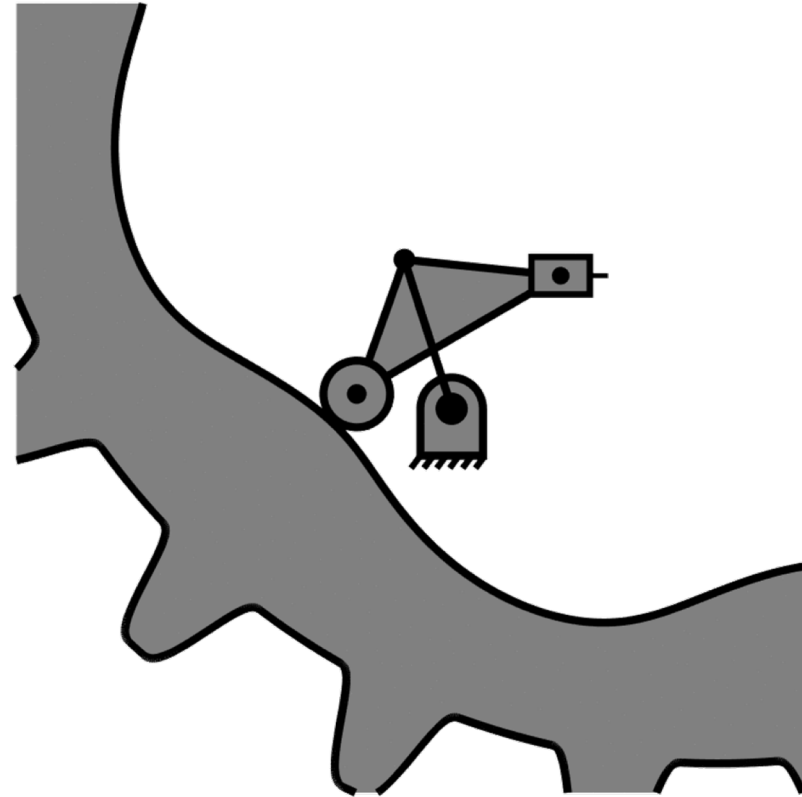
- Radius of curvature
- Center of curvature
- Normal vector
- Pressure angle





# Kinetics

- Force balance
- Torque ripple
- Bearing sizing
- Interference detection



# Acknowledgement

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