Compact, electro-hydraulic, variable valve actuation system providing variable lift, timing and duration to enable high efficiency engine combustion control

High-Efficiency Engine Technologies

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U.S. DEPARTMENT OF ENERGY
DEER 2012
DEARBORN
DIRECTIONS IN ENGINE-EFFICIENCY AND EMISSIONS RESEARCH CONFERENCE

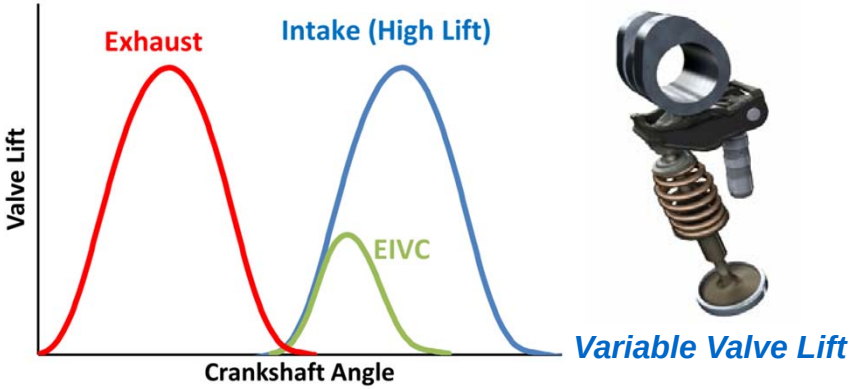
Outline

- Background
- Cam-Camless System
  - System Layout
  - Actuator Operation
  - Valve Profile Flexibility
- Results
  - Accuracy and Repeatability
  - Energy Recovery
- Conclusions

Background
Fuel Efficiency

- Push for passenger car fuel economy
  - 35.5 mpg by 2016
  - 54.5 mpg by 2025

- Valvetrain fuel economy benefits with
  - Cylinder deactivation
  - Camshaft Phasing
  - Variable Valve Lift



- Heavy Duty Efficiency Goals
  - 55% Brake Thermal Efficiency (Supertruck)
  - 50% Freight Efficiency Improvement (Supertruck)

Maintain standard valve profiles plus more flexibility using electro-hydraulic actuation

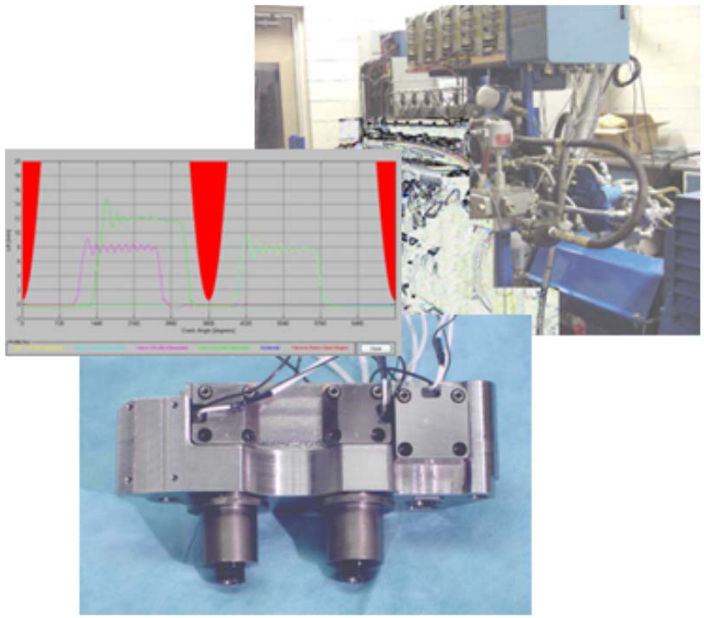
Background
Camless Historical Development

1990's: Light Duty Camless

- Dual-acting, electro-hydraulic actuation
- Fixed lift, variable timing & duration

2000's: Heavy Duty Camless

- Single-acting, electro-hydraulic actuation
- Fully variable – lift, timing & duration



Common Hurdles:

- Cost
  - Efficiency
    - Compactness

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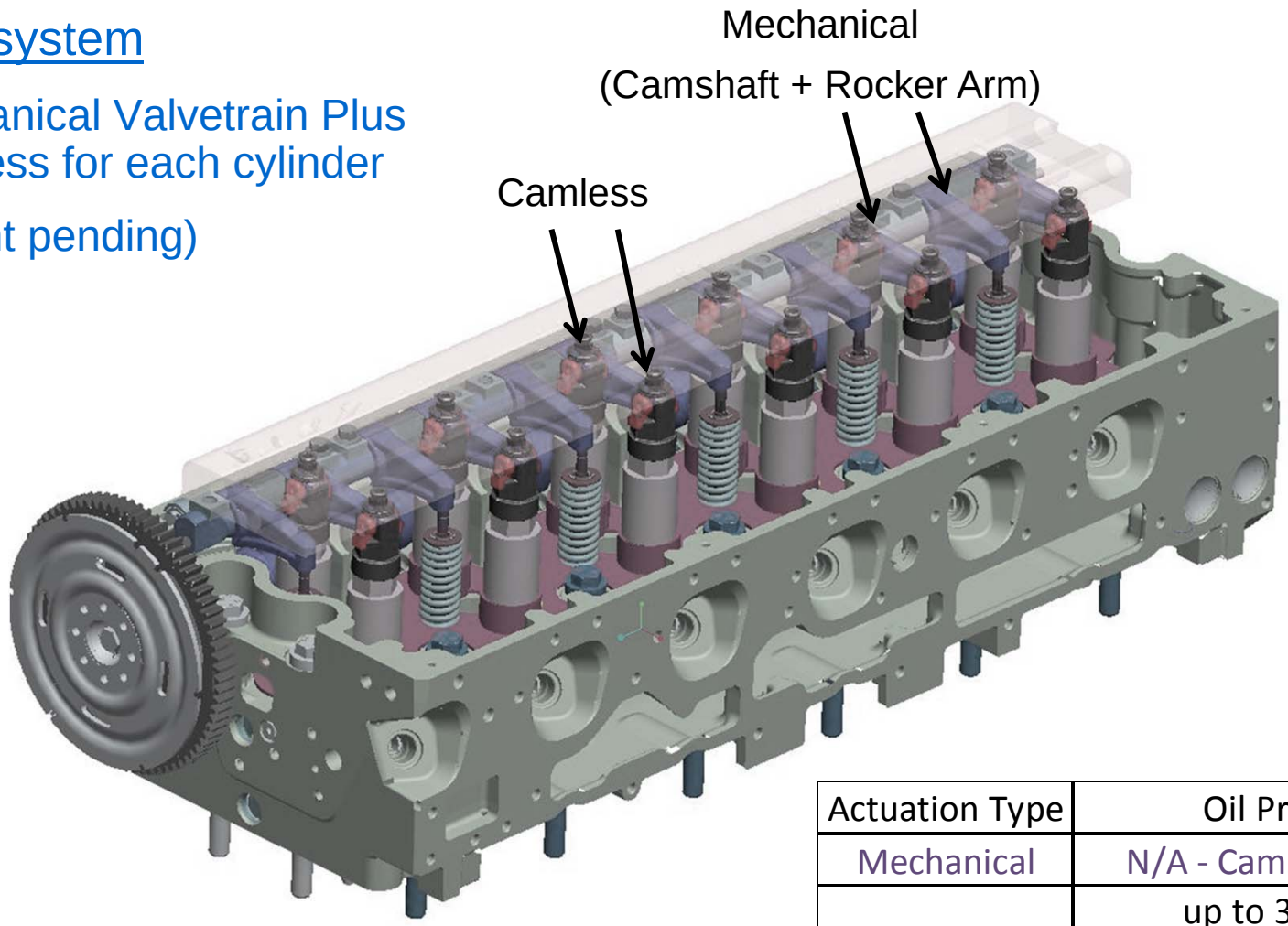
Cam-Camless Configuration
Heavy Duty System Layout (1 of 2)

Hybrid system

- Mechanical Valvetrain Plus Camless for each cylinder

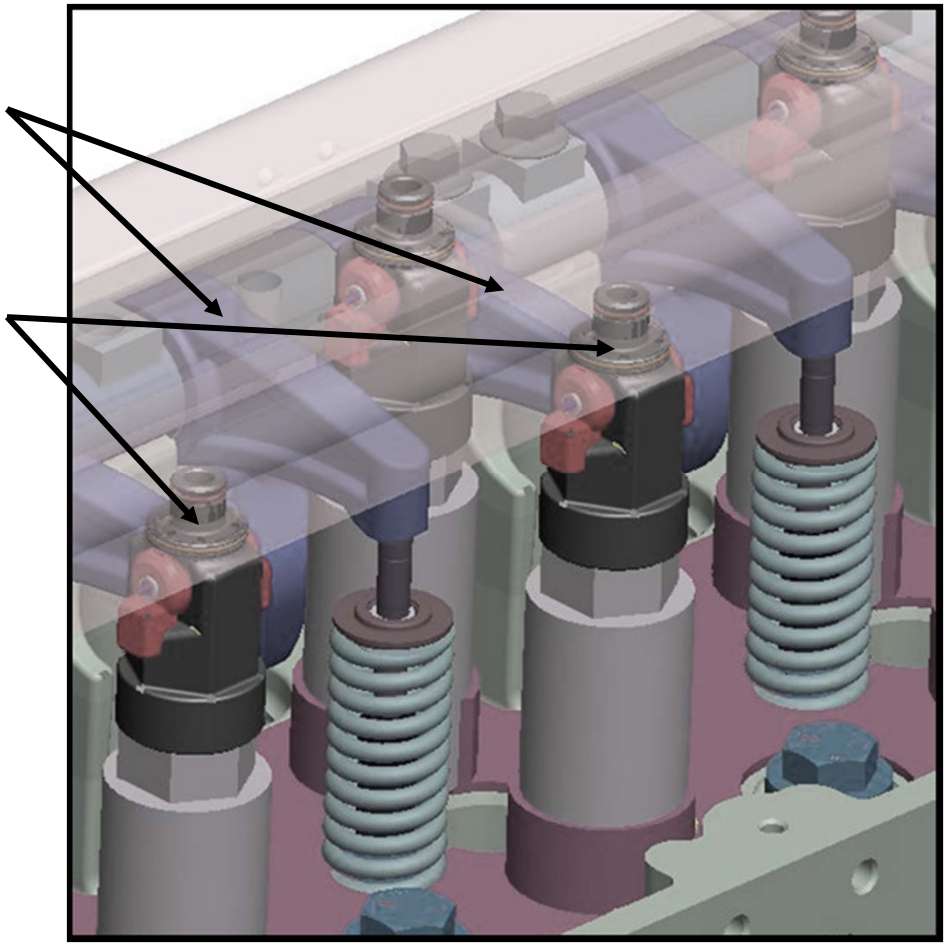
  (patent pending)



Actuation Type	Oil Pressure
Mechanical	N/A - Camshaft Based
Camless	up to 3000 psi (normal 500 to 2000 psi)

Cam-Camless Configuration
Heavy Duty System Layout (2 of 2)

- Standard mechanical valvetrain independently actuates 1-intake and 1-exhaust for each cylinder
- Camless independently actuates the remaining intakes & exhausts
- Benefits
  - Equivalent package space as an engine with a brake
  - Mechanical system offers both start-up and limp-home capabilities
  - Stepping stone to full camless



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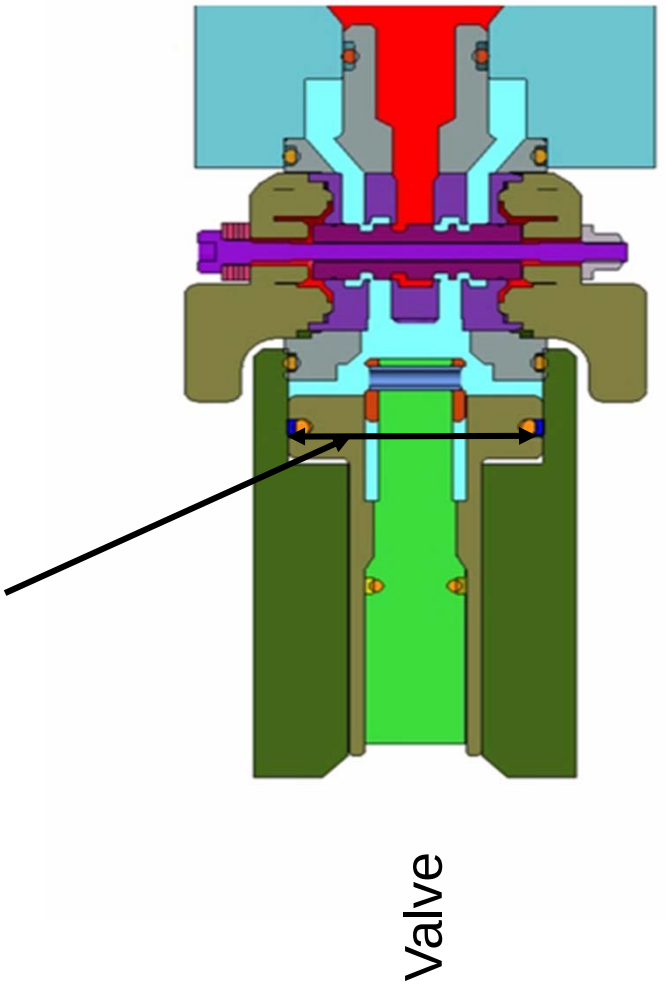
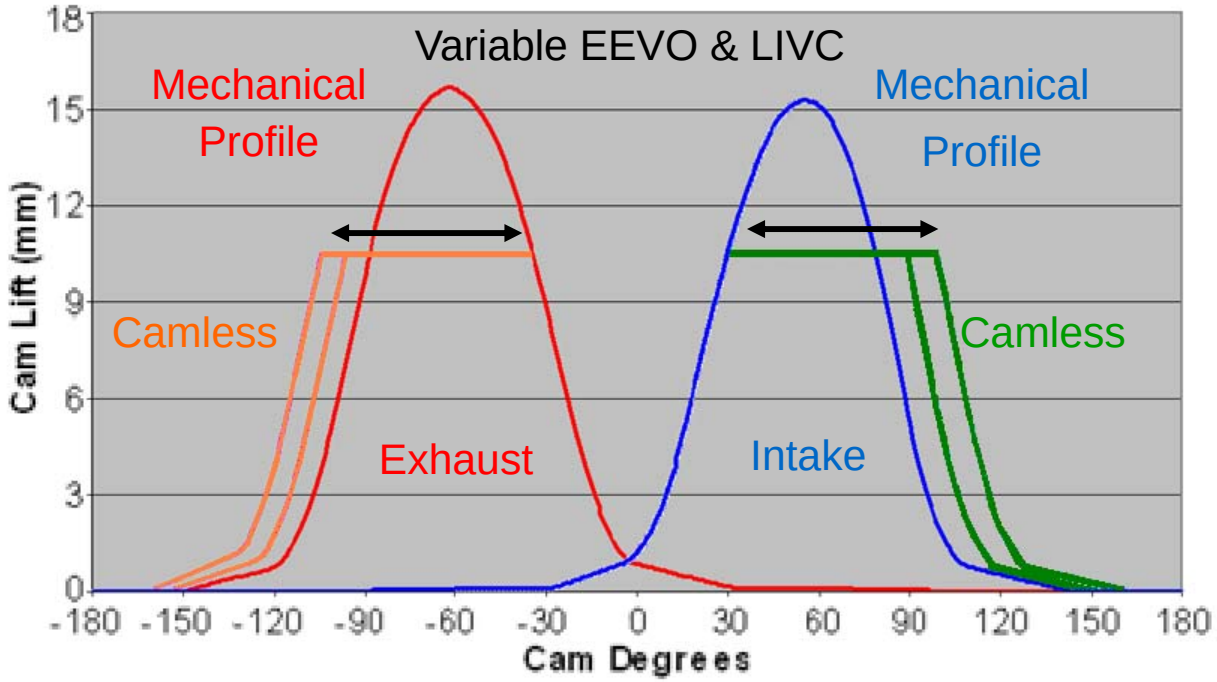
Cam-Camless
Actuation Operation

- Simple 3-position hydraulic actuator control lift
  1. No lift
  2. Valve fully open
  3. Valve partially open (ex. braking)
- Travel is limited by stops built into actuation assembly
- Large diameter piston provides
  - seating velocity
  - braking capability – controlled by pressure



Cam-Camless
Valve Profile Flexibility

- Mechanical valvetrain applied to half of engine valves
- Camless actuation applied to remaining valves
  - Infinitely variable timing and duration
- Fixed lift to maximize benefits and reduce complexity
  - Minimize energy loss while maintaining system operation



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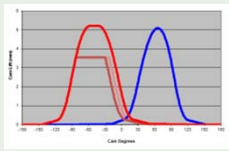
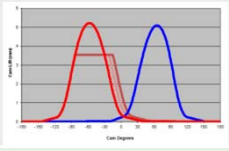
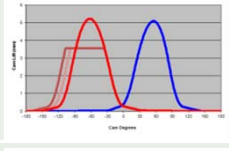
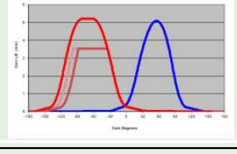
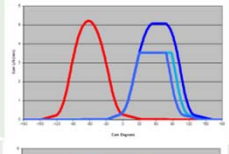
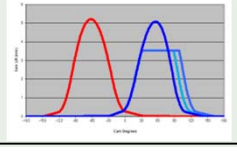
Cam-Camless
Multiple Profiles Available

STRATEGY	VALVE EVENT	CAM	EH-VVA
EARLY EVC		Fixed	Fully Var.
LATE EVC		Fixed	Fully Var.
EARLY EVO		Fixed	Fully Var.
LATE EVO		Fixed	Fully Var.
EARLY IVC		Fixed	Fully Var.
LATE IVC		Fixed	Fully Var.

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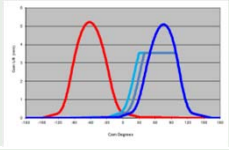
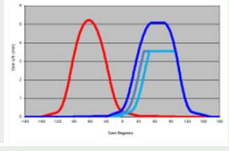
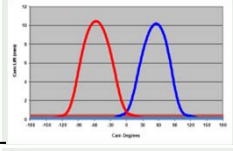
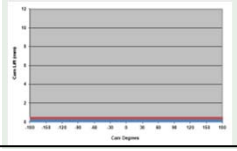
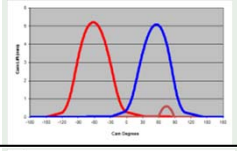
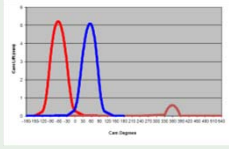
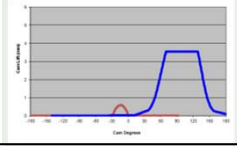
EARLY IVO		Fixed	Fully Var.
LATE IVO		Fixed	Fully Var.
SWIRL		Fixed	Not Active
CYL. DEAC.		Fixed (Req. Deac. Rockers)	Not Active
Internal-EGR		Fixed	1-Step Fully Var.
4-Stroke Braking		Fixed	1-Step Fully Var.
2-Stroke Braking		Fixed (Req. Deac. Rockers)	1-Step Fully Var.

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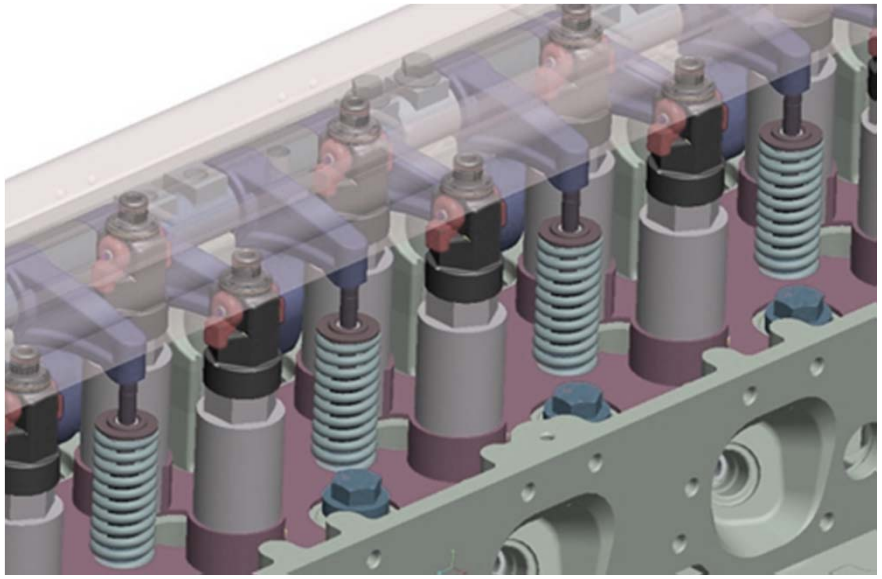
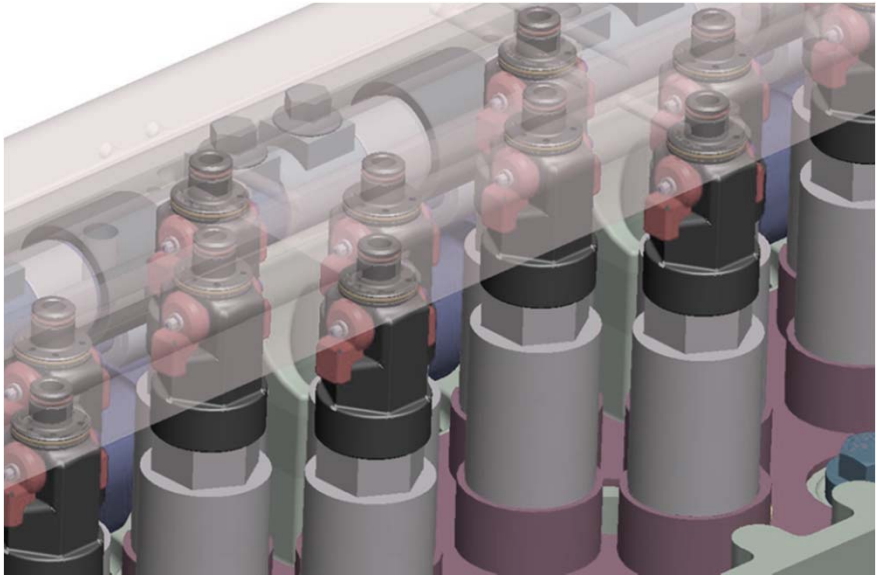
Cam-Camless

Compatibility to Full Camless

Cam-Camless



Full Camless



Cam-Camless architecture is upward compatible to full camless

Outline

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  - System Layout
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  - Valve Profile Flexibility
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  - Accuracy and Repeatability
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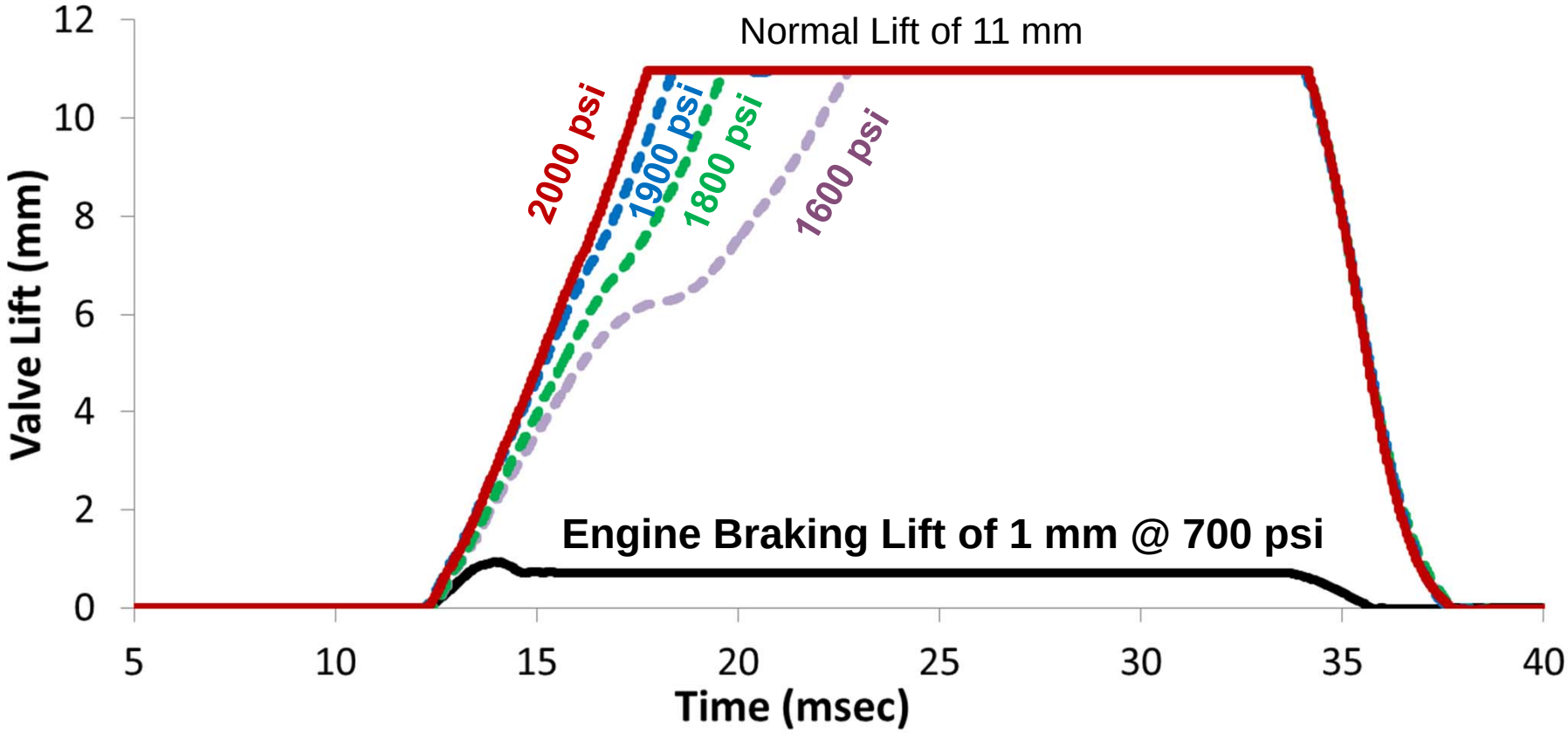
Actuation Test Results (1 of 3)
Normal and Braking Lift

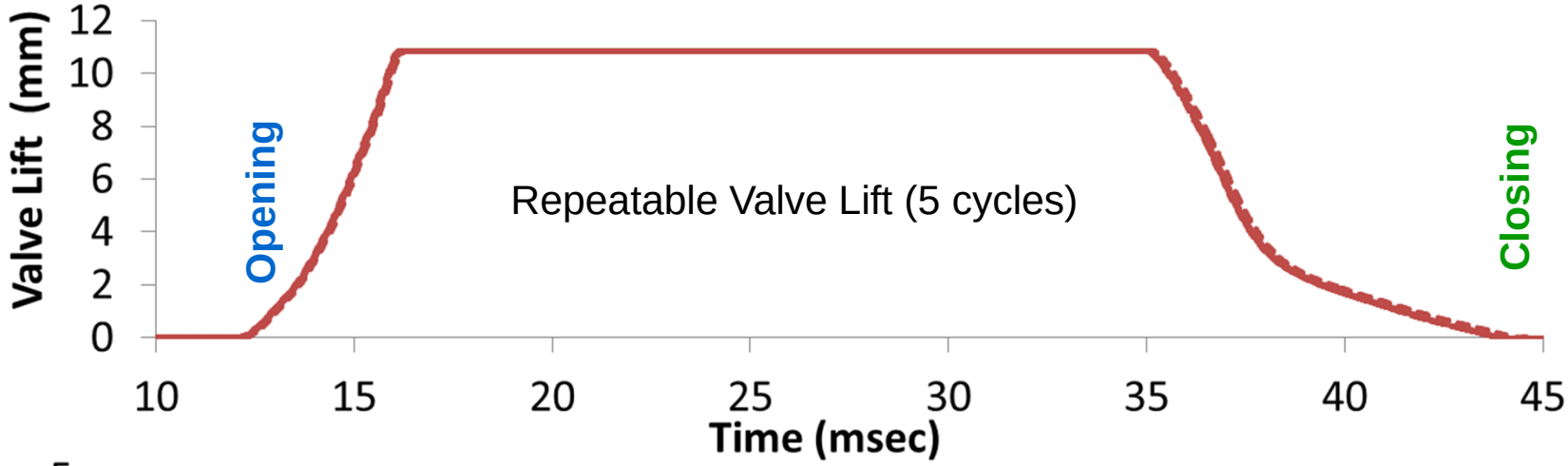


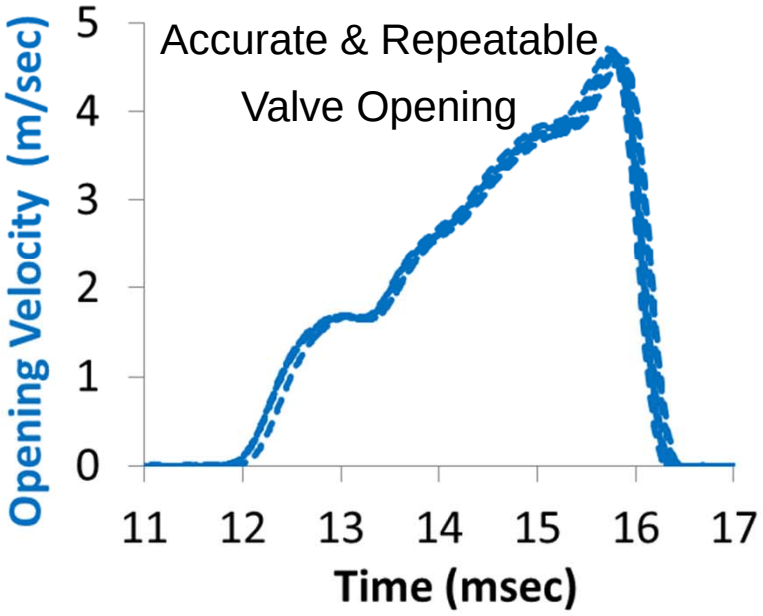
Modular Lift Profiles Available as Function of Actuation Pressure

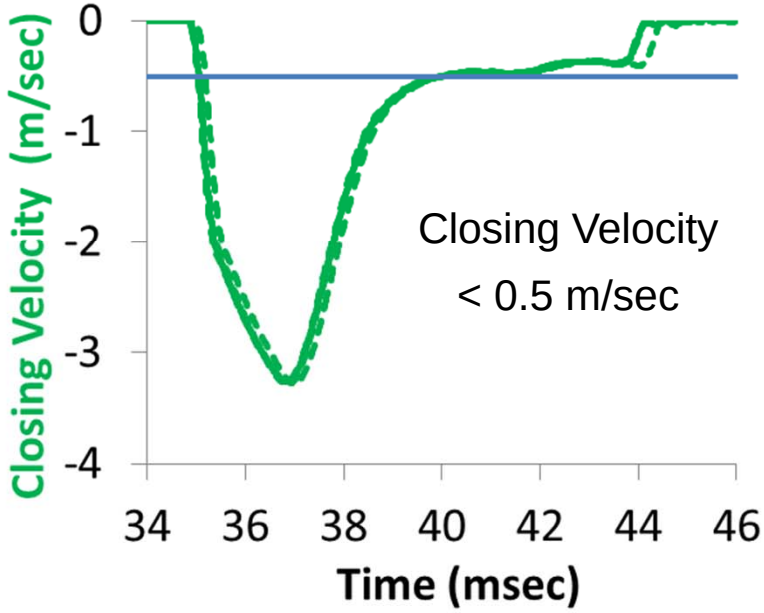
1. Normal Lift of 11 mm (1800 to 2000 psi)
2. Braking Lift of 1 mm (700 psi)

Actuation Test Results (2 of 3)

Accuracy & Repeatability: 2000 psi actuation pressure







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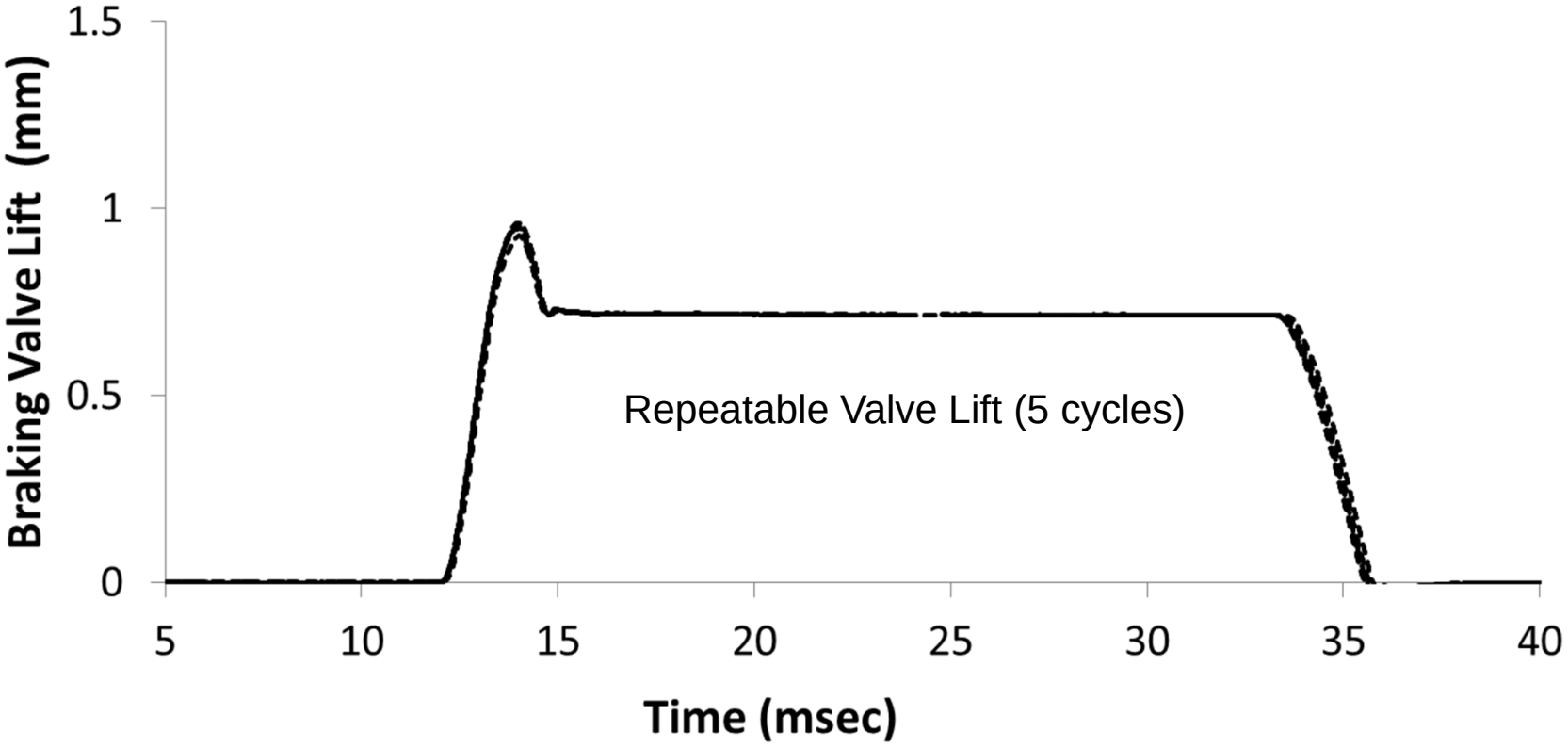
Actuation Test Results (3 of 3)
Accuracy & Repeatability: 700 psi actuation pressure



Engine braking Lift of 1 mm at 700 psi with flexible timing and duration

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Simulation Results

Power Consumption

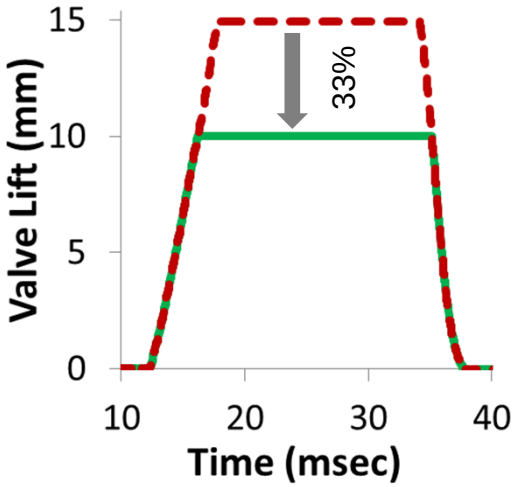
Two Paths to Reduce Actuation Power Consumption

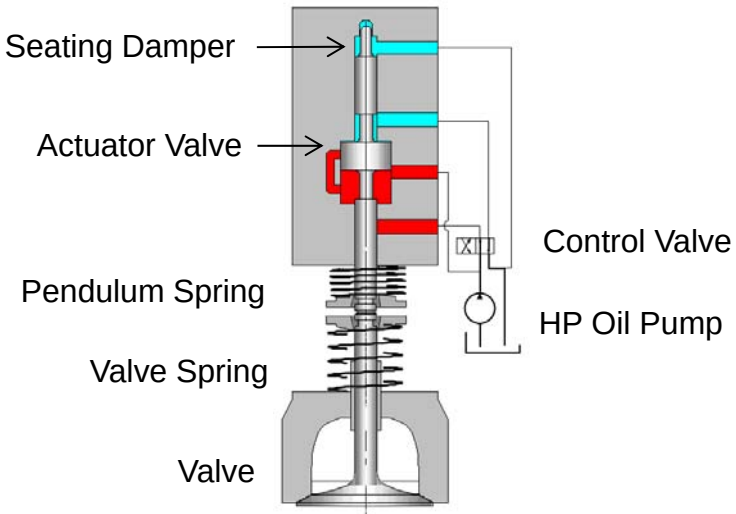
1. Reduce lift

- Energy consumption is proportional to maximum lift
- ~33% improvement by reducing lift (15 to 10 mm)

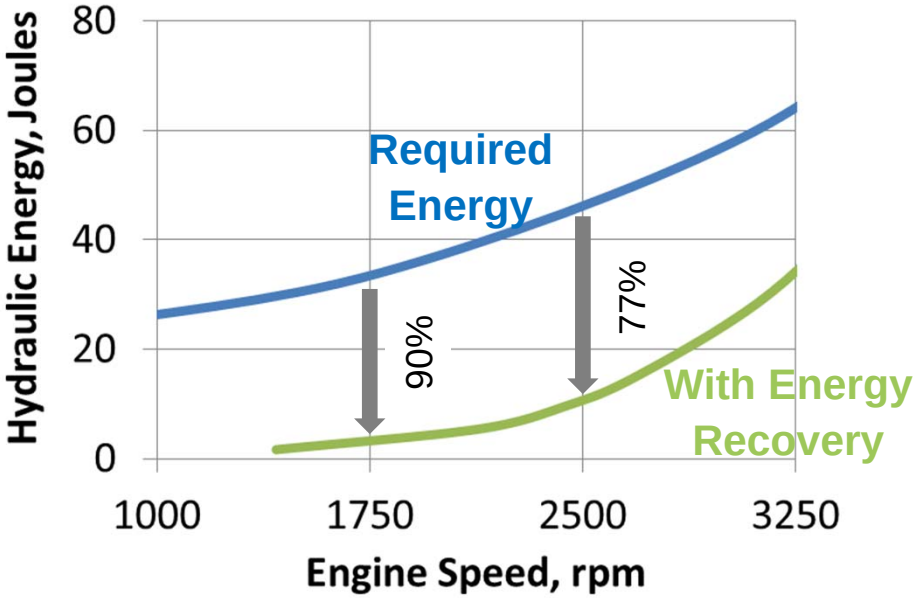
2. Energy Recovery using an Electro-Hydraulic Pendulum Actuator

- Pendulum Actuator offers improved efficiency
  - 90% improvement @ 1750 rpm (3J vs. 34J)
  - 77% improvement @ 2500 rpm (11J vs. 47J)





Ref.: US Patent 5,248,123



Conclusions

- Cam-Camless System
  - Offers valvetrain flexibility
  - Maintains benefits of a mechanical system
  - Architecture upward compatible to full camless
- Camless Actuators
  - Fits within current envelope containing an engine brake
  - Three position actuator to simplify complexity
  - Actuation proven repeatable and accurate
  - Energy recovery possible from 33% to 90%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