Free Piston Engine Based Off-Road Vehicles

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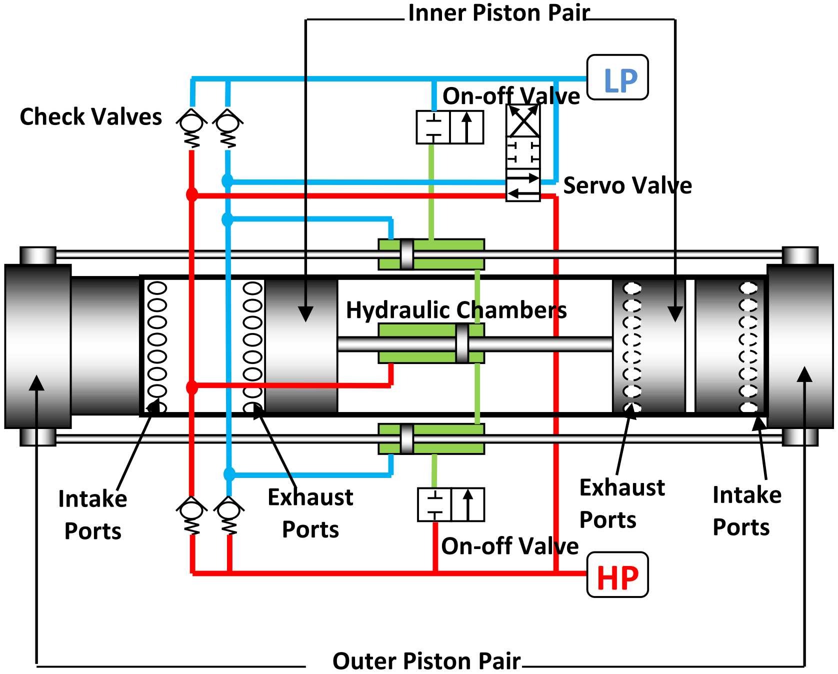
Outline

- Project overview
- Realization of Independent pressure and flow control
  - Basic principle and efficiency analysis
  - Robust realization
- Consecutive combustion tests
  - Scavenging improvement
  - Consecutive combustion test results
- Summary and future work

Recap:
OPOC FPE and Previous Work

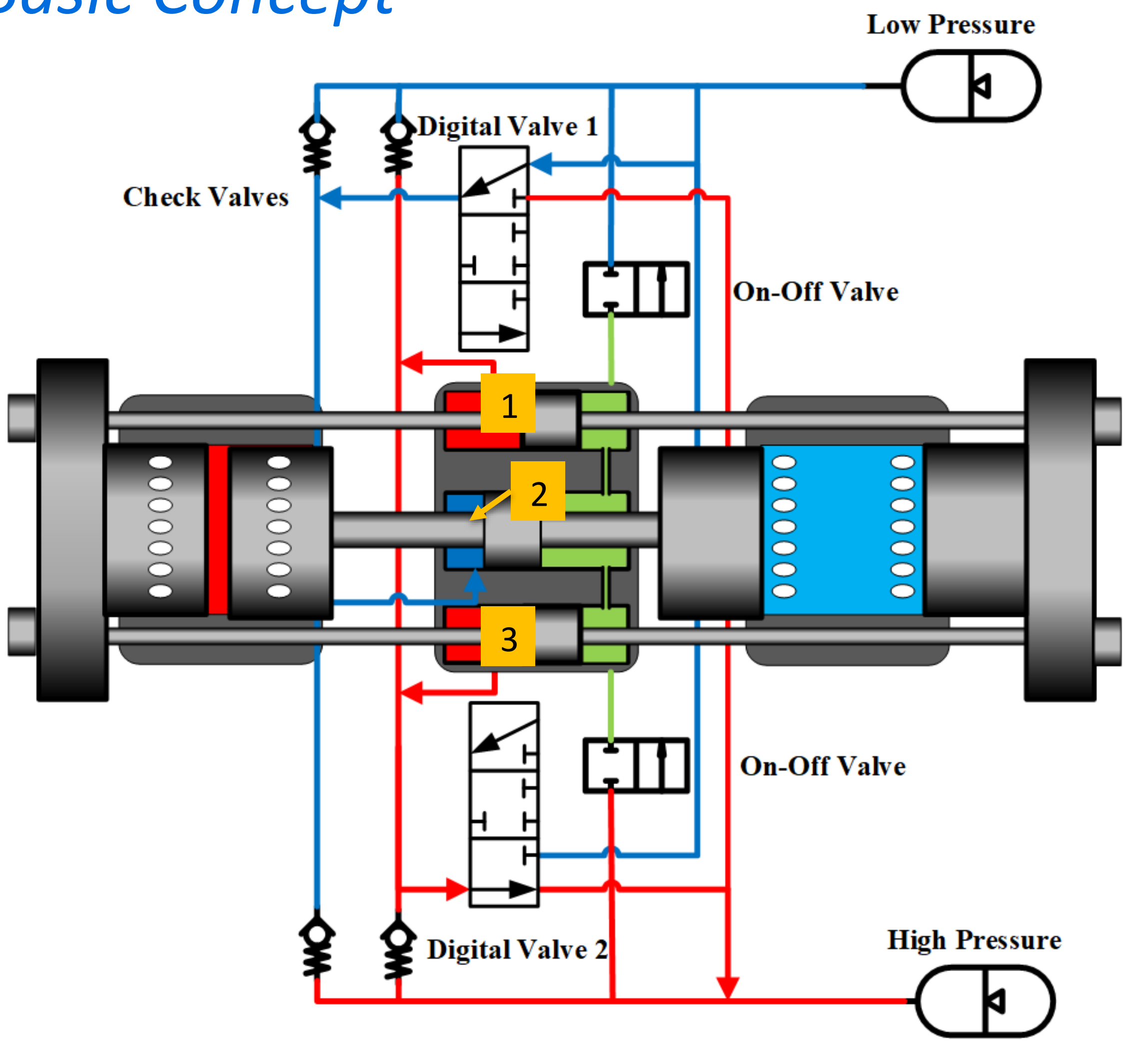


Modular and flexible fluid power source that removes or reduces throttling loss

- Previous work
  - Improvement of hardware
  - System modeling
  - Virtual crankshaft
    - Motoring
    - Combustion
  - Trajectory based combustion control

Independent Pressure and Flow Rate Control

Basic Concept



Flow from Chamber 1&3

60%

Flow to Chamber 2

60%

Flow to High Pressure

60%

Independent Pressure and Flow Rate Control

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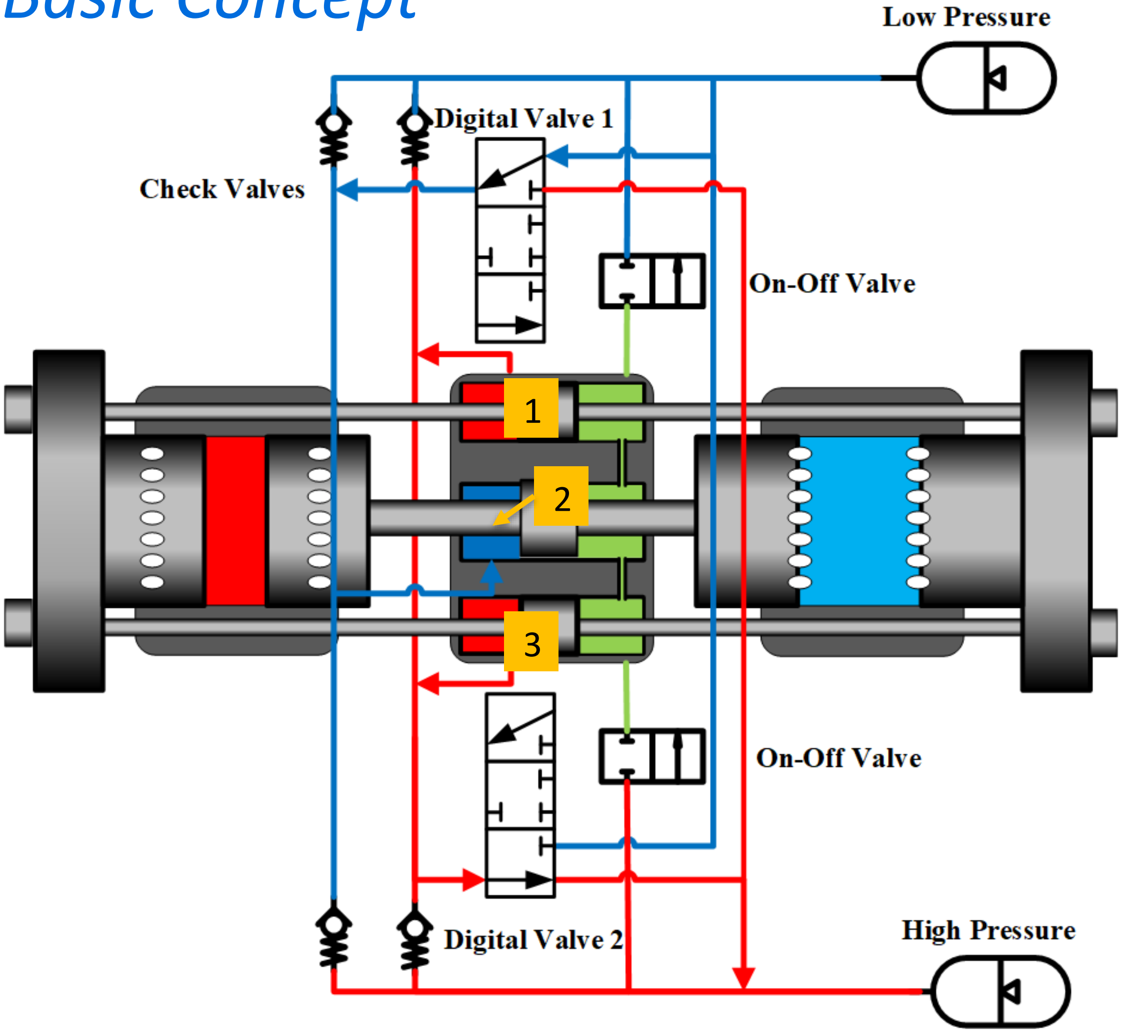

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Flow to High Pressure

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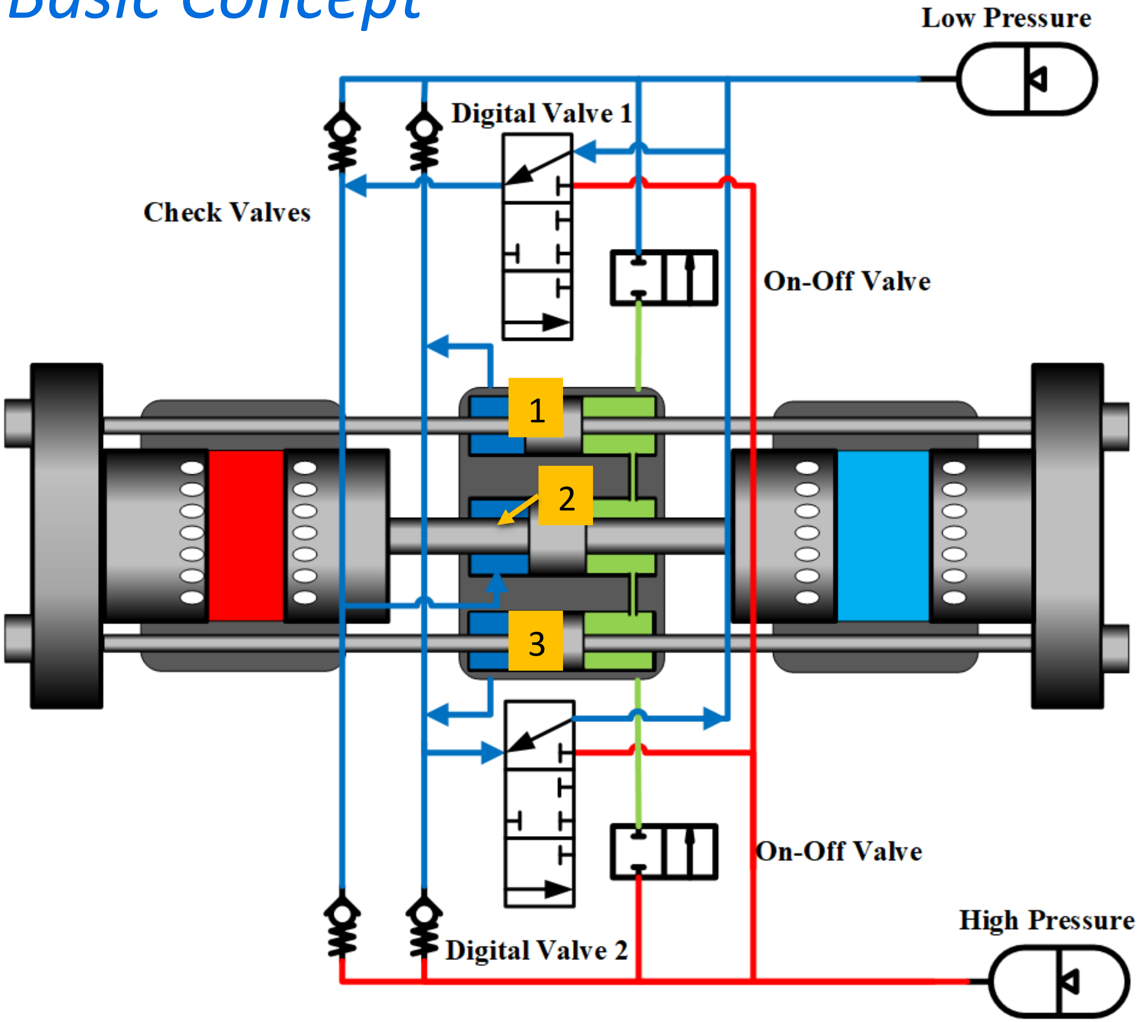

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60%

Flow to Chamber 2

60%

Flow to High Pressure

60%

Independent Pressure and Flow Rate Control

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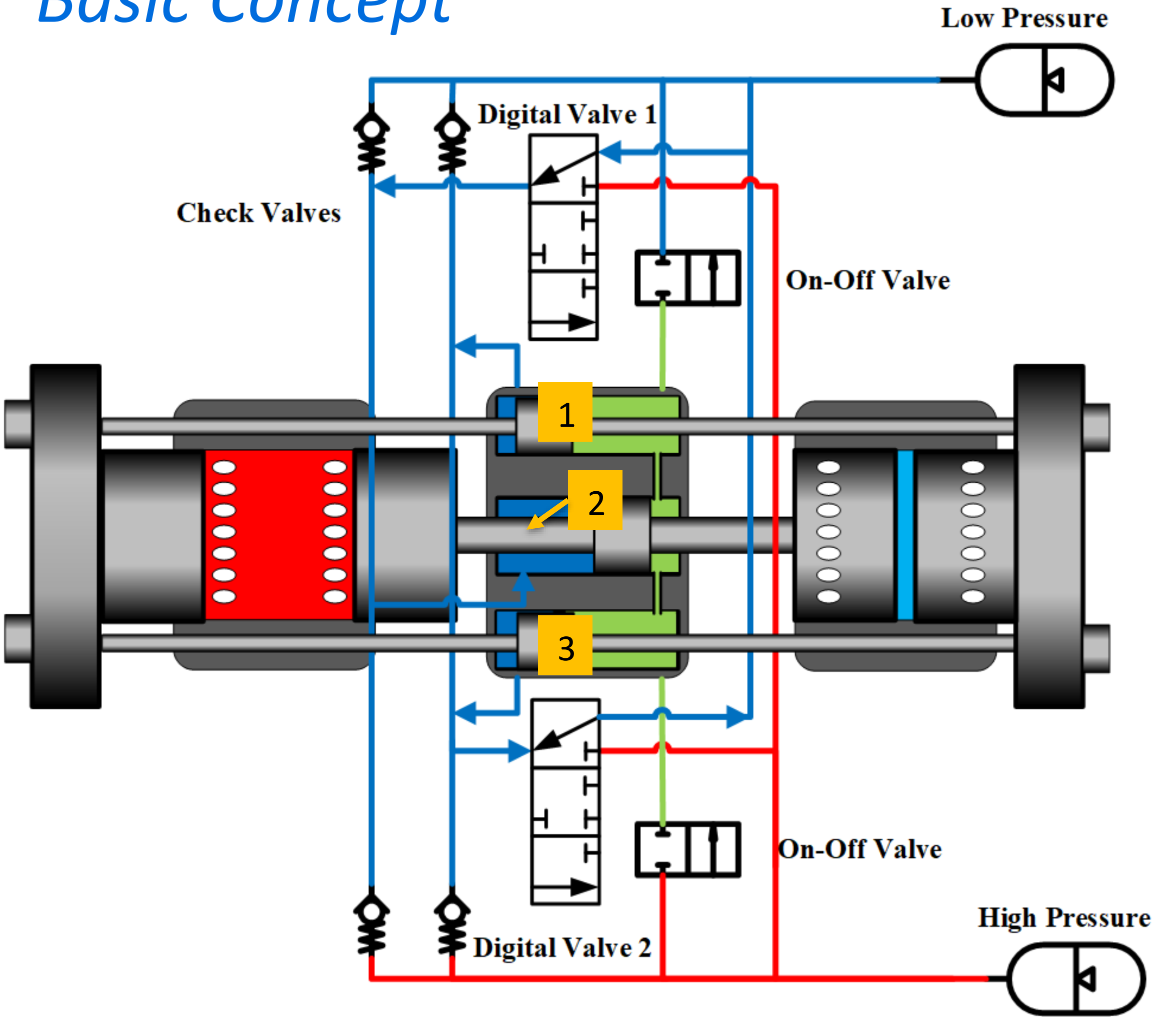


Flow from Chamber 1&3

60%	40%

Flow to Chamber 2

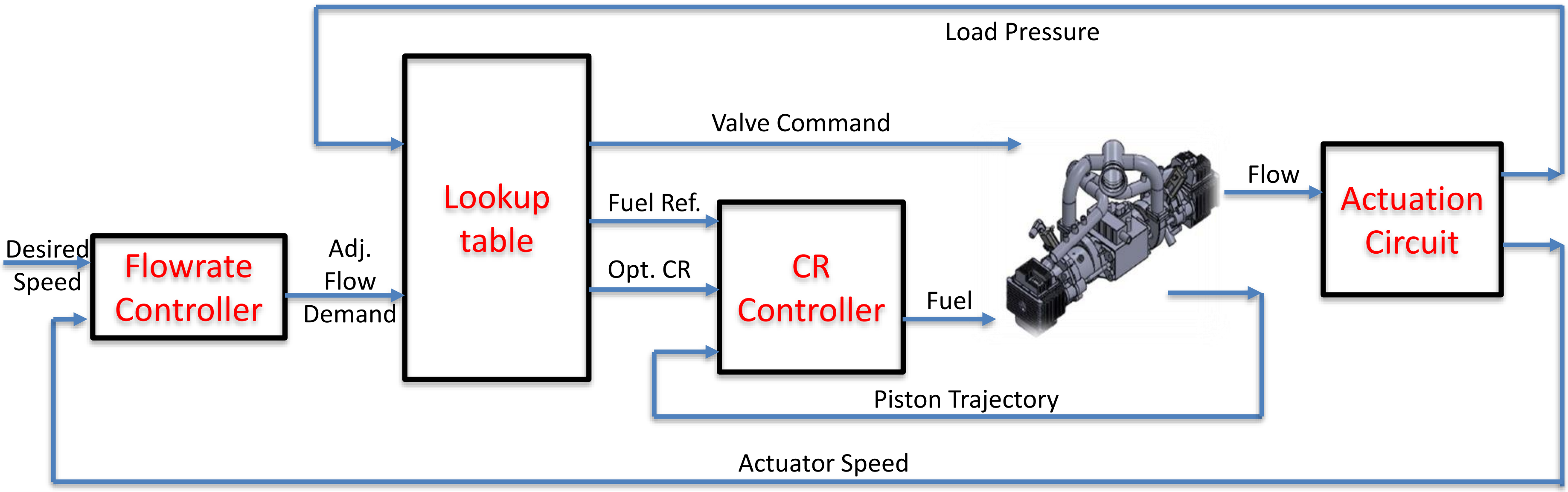
60%	40%

Flow to High Pressure

60%	0%

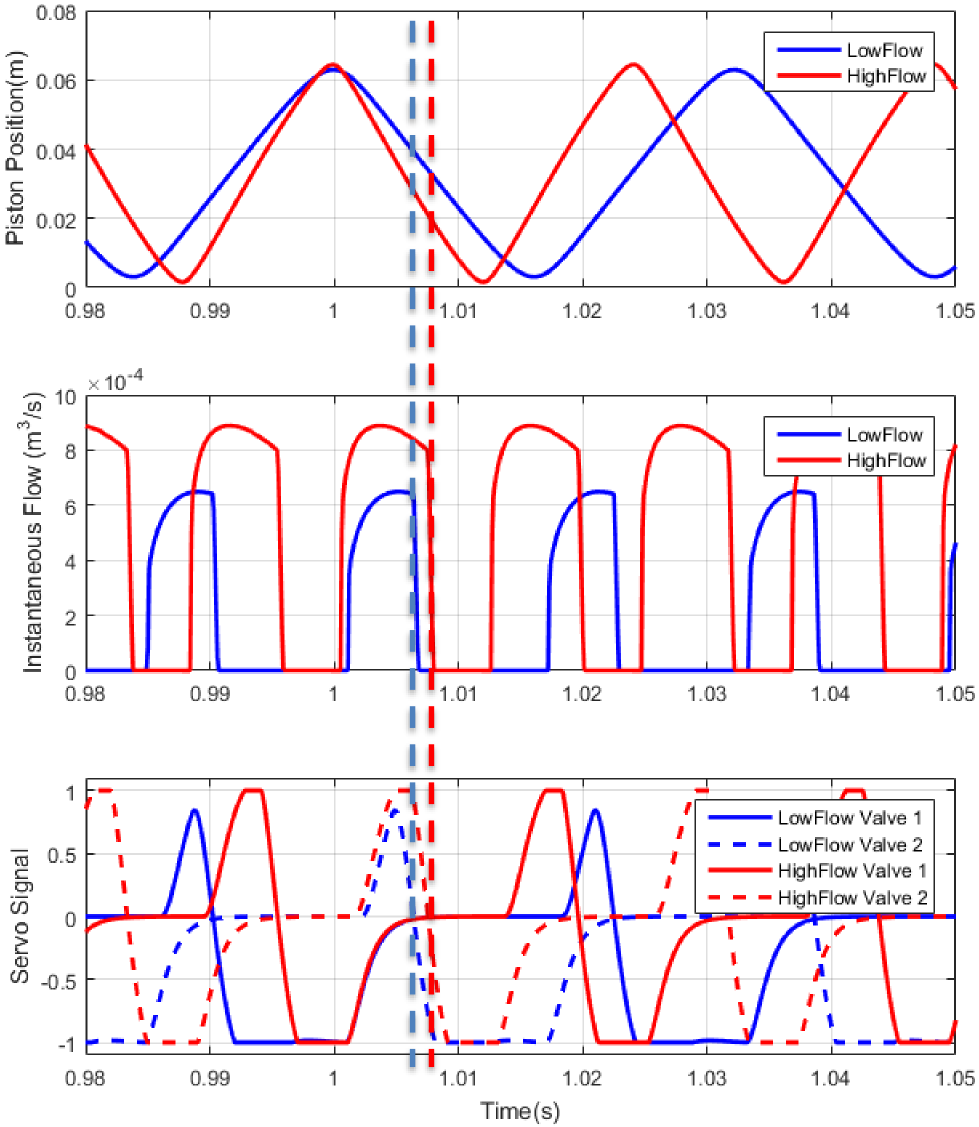
Independent Pressure and Flow Rate Control

Realization: General Structure



- A feedforward controller provide the fuel amount reference, valve command and optimal operation CR reference based on the load pressure and flow rate demand
- A feedback CR controller calculate the actual CR of the FPE adjust the fuel amount to track the CR reference
- An outer loop feedback controller adjust the flow command to the feedforward controller based on actual flow rate to track the flow demand from user

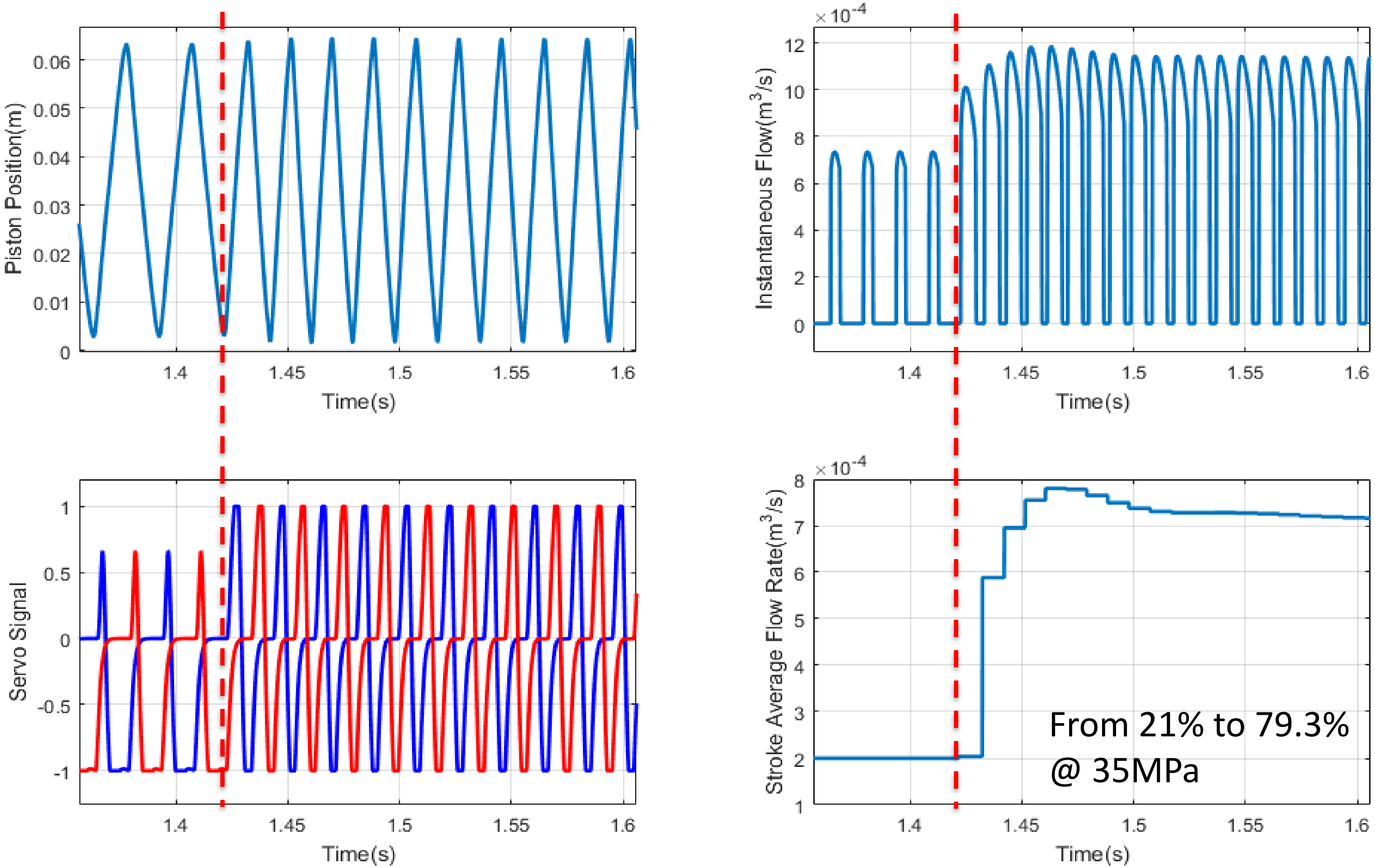
Simulation Result



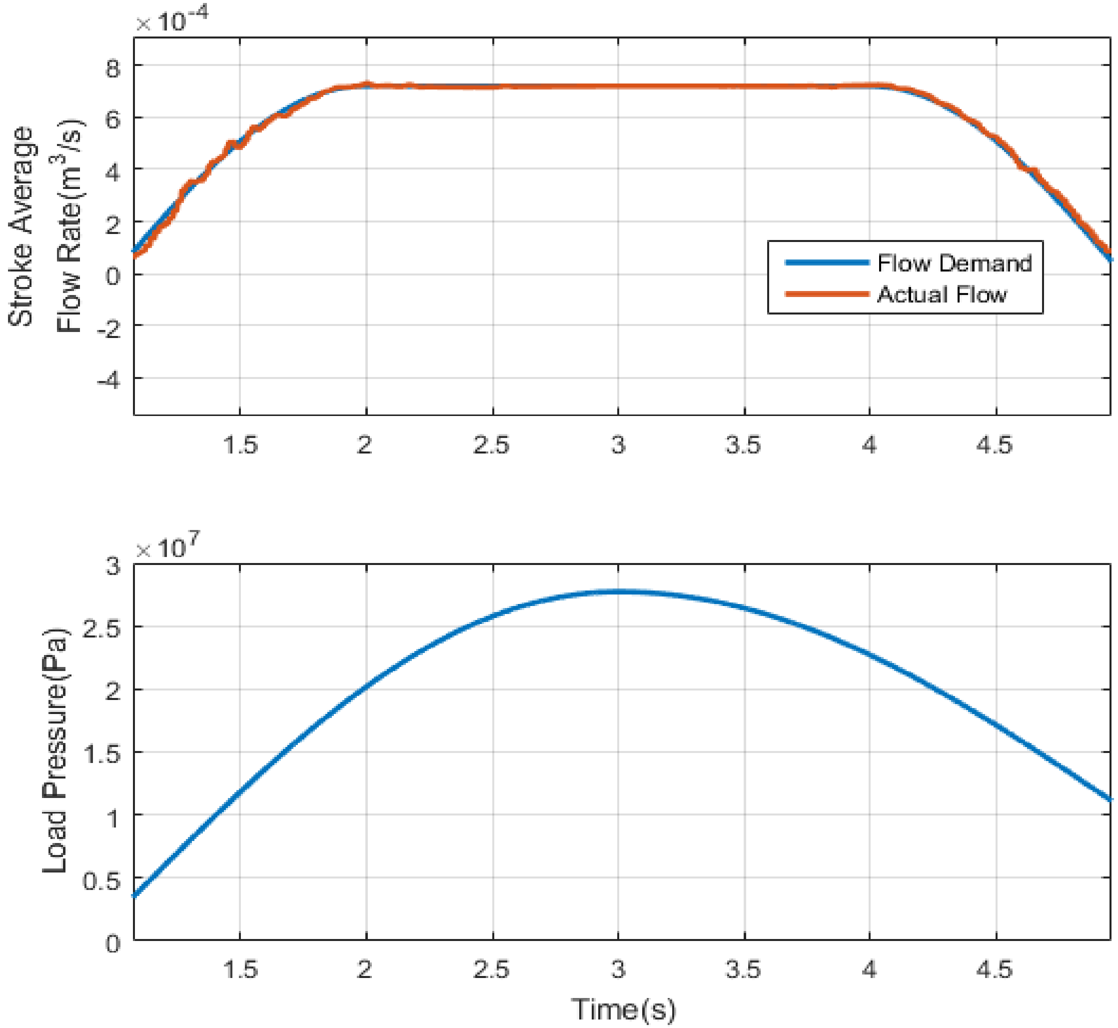
- The FPE operates stably under IPFC
- The instantaneous flow shows the predicted profile
- The flow rate can be properly controlled under steady states.

Pressure: 15MPa
High Flow: $5\times10^{-4} m^3/s$, or 65.5%
Low Flow: $2\times10^{-4} m^3/s$, or 26.2%

Simulation Result



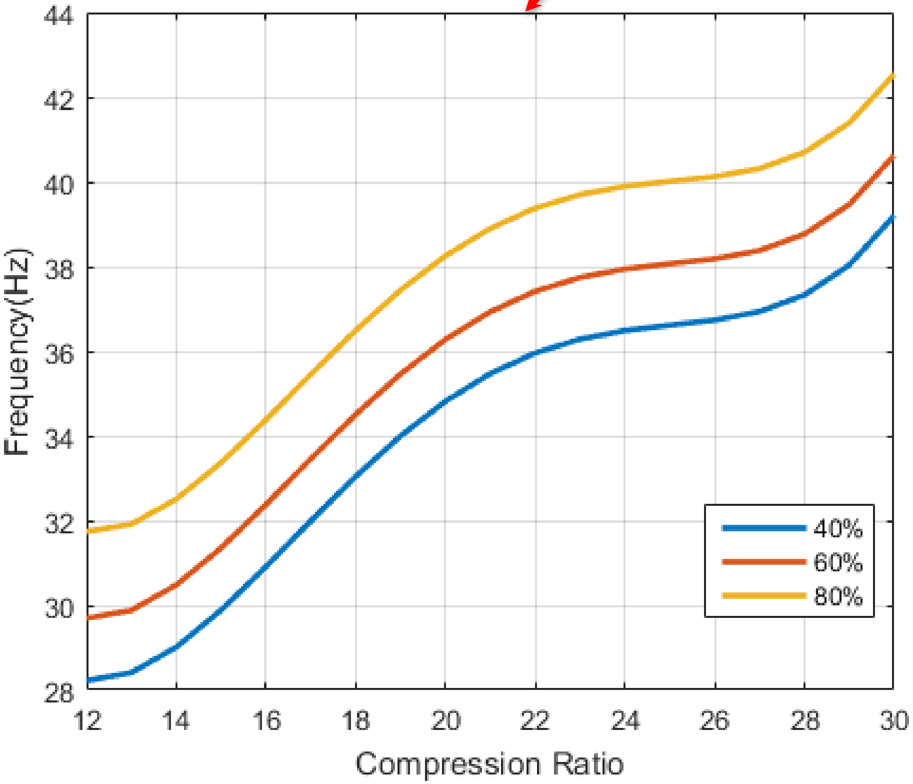
Simulation Result

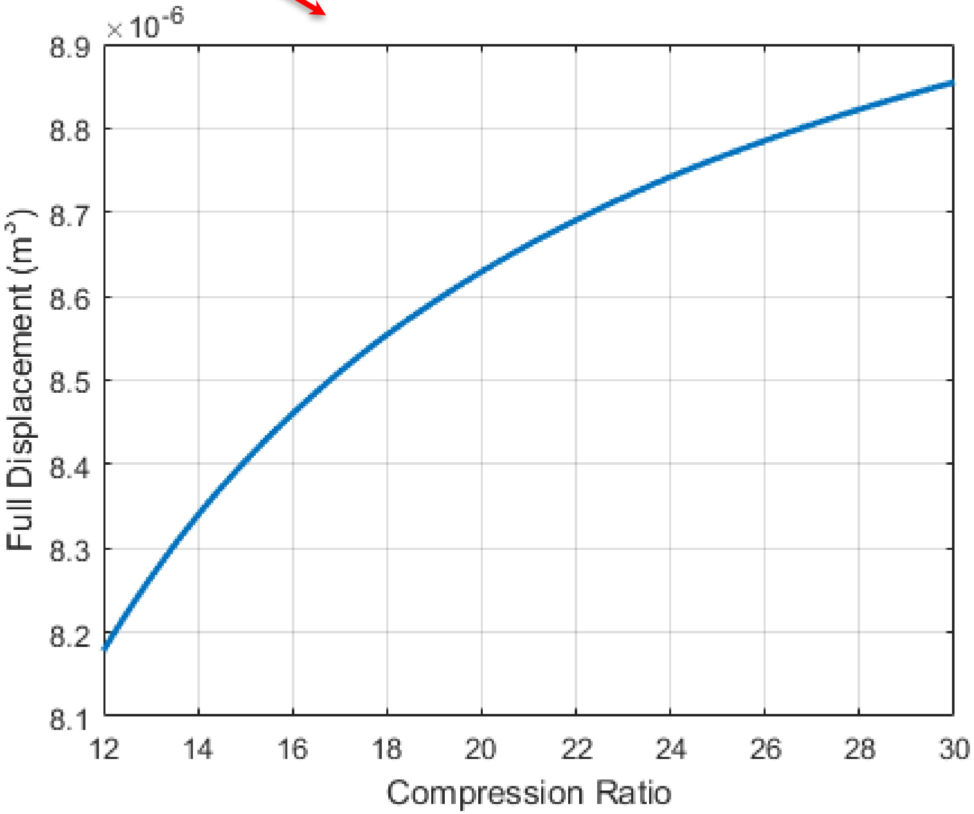


- The flow rate demand can be properly tracked under continuously changing load pressure.
- The step response time of the system is in the order of tens of milliseconds.

Optimal working parameter

$$Q_{output} = \boxed{f_{op.}(CR, \gamma_d)} \cdot \gamma_d \cdot \boxed{V_0\ (CR)}$$





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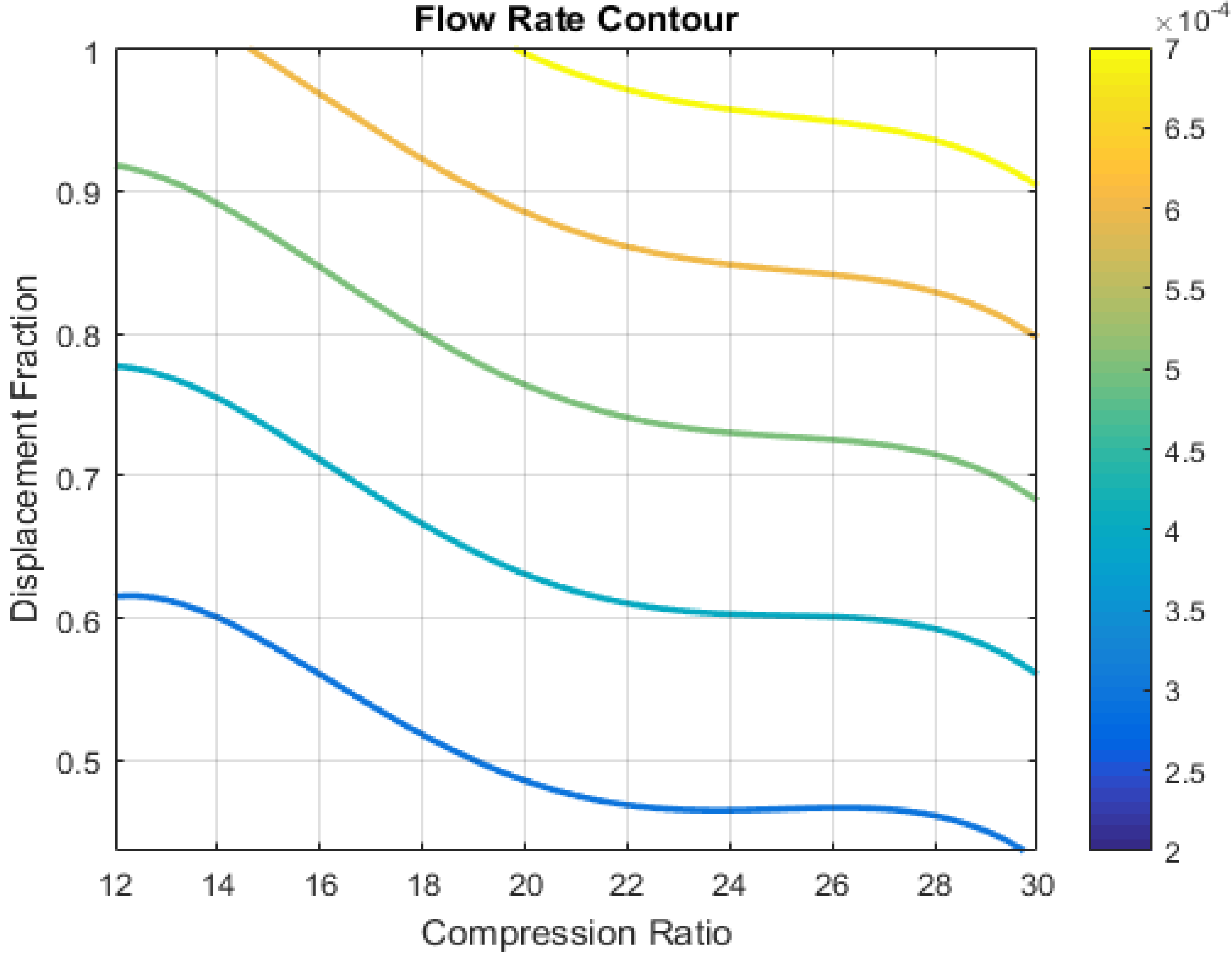
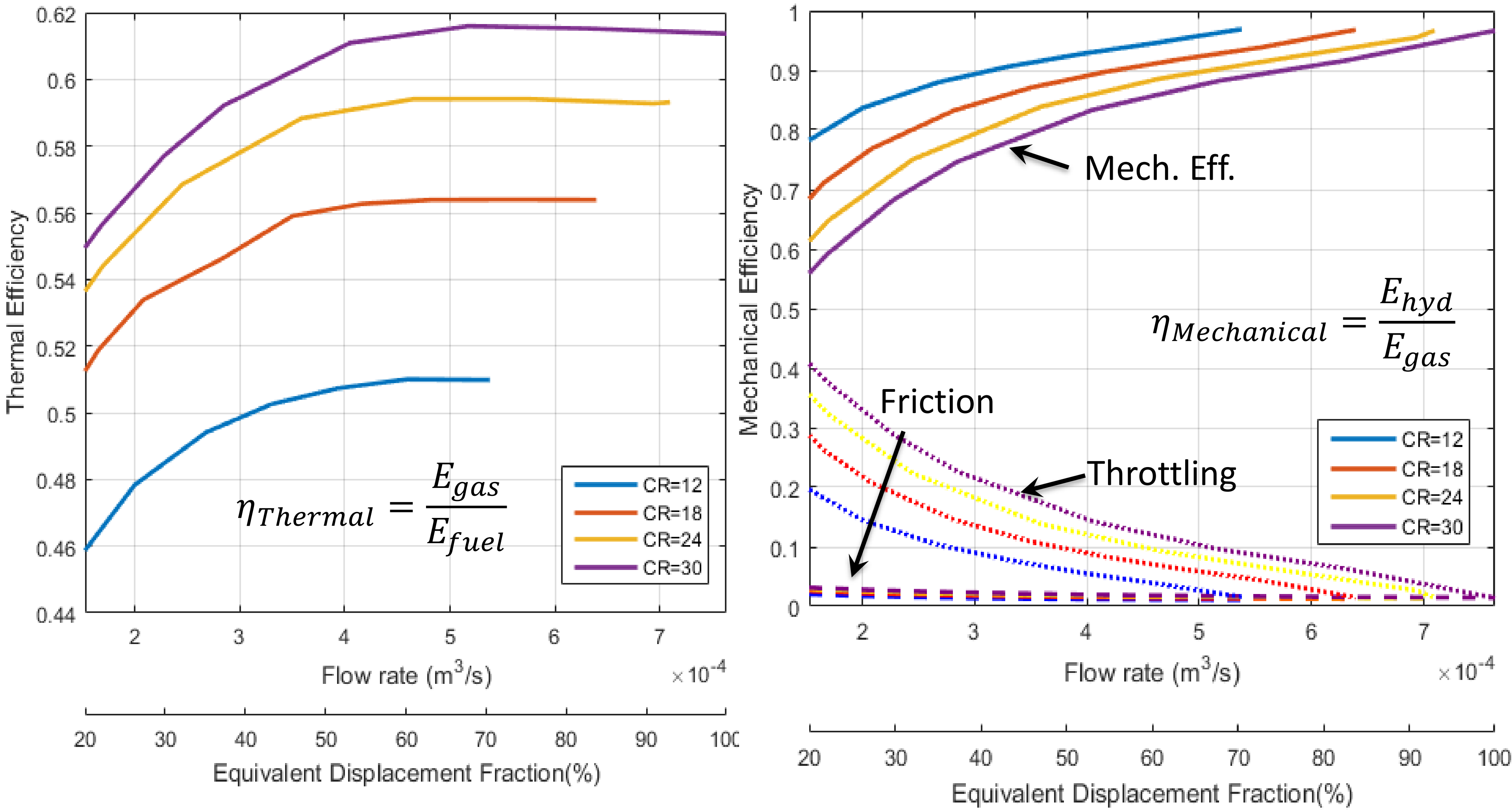


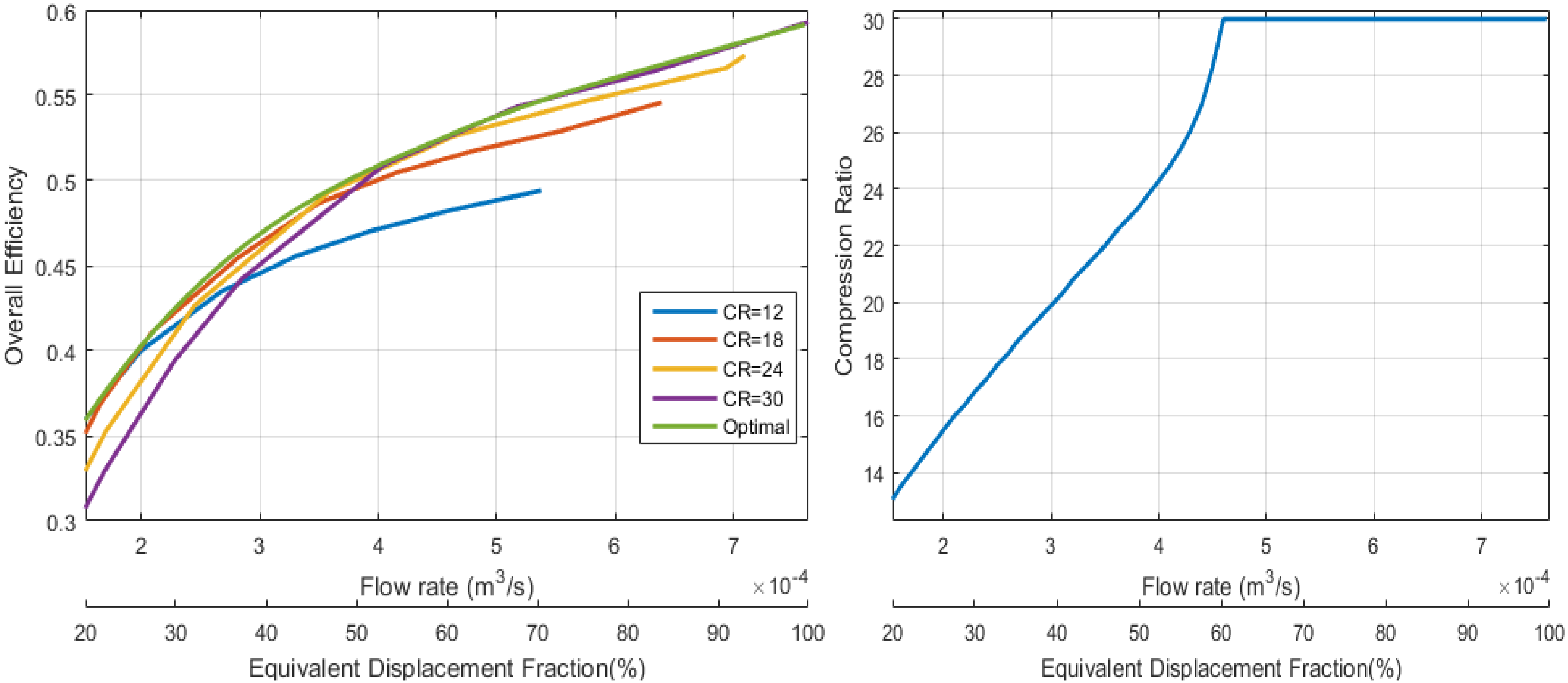
Pressure: 15MPa

Efficiency Analysis



Pressure: 15MPa

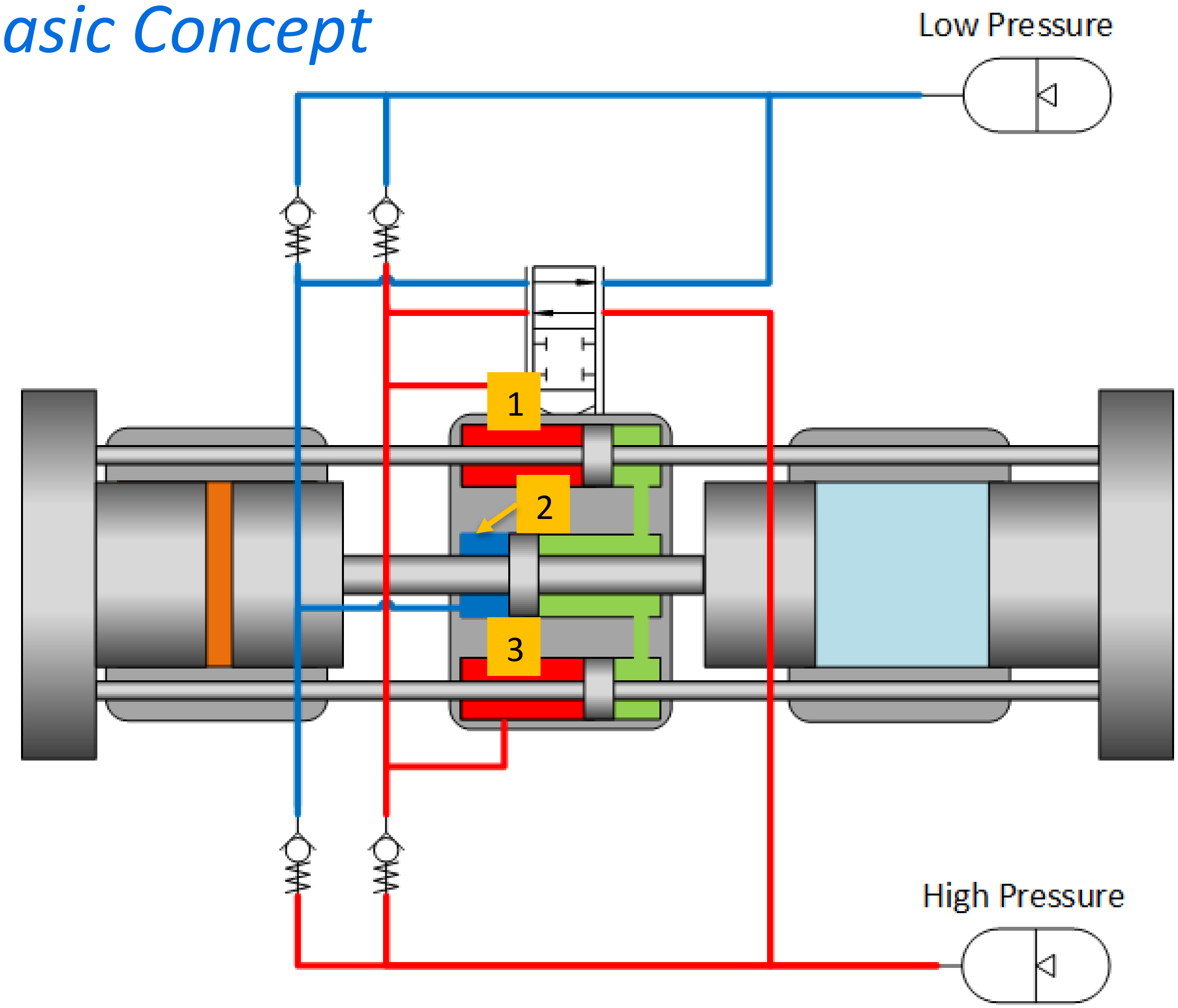
Efficiency Analysis



Pressure: 15MPa

Independent Pressure and Flow Rate Control

Basic Concept



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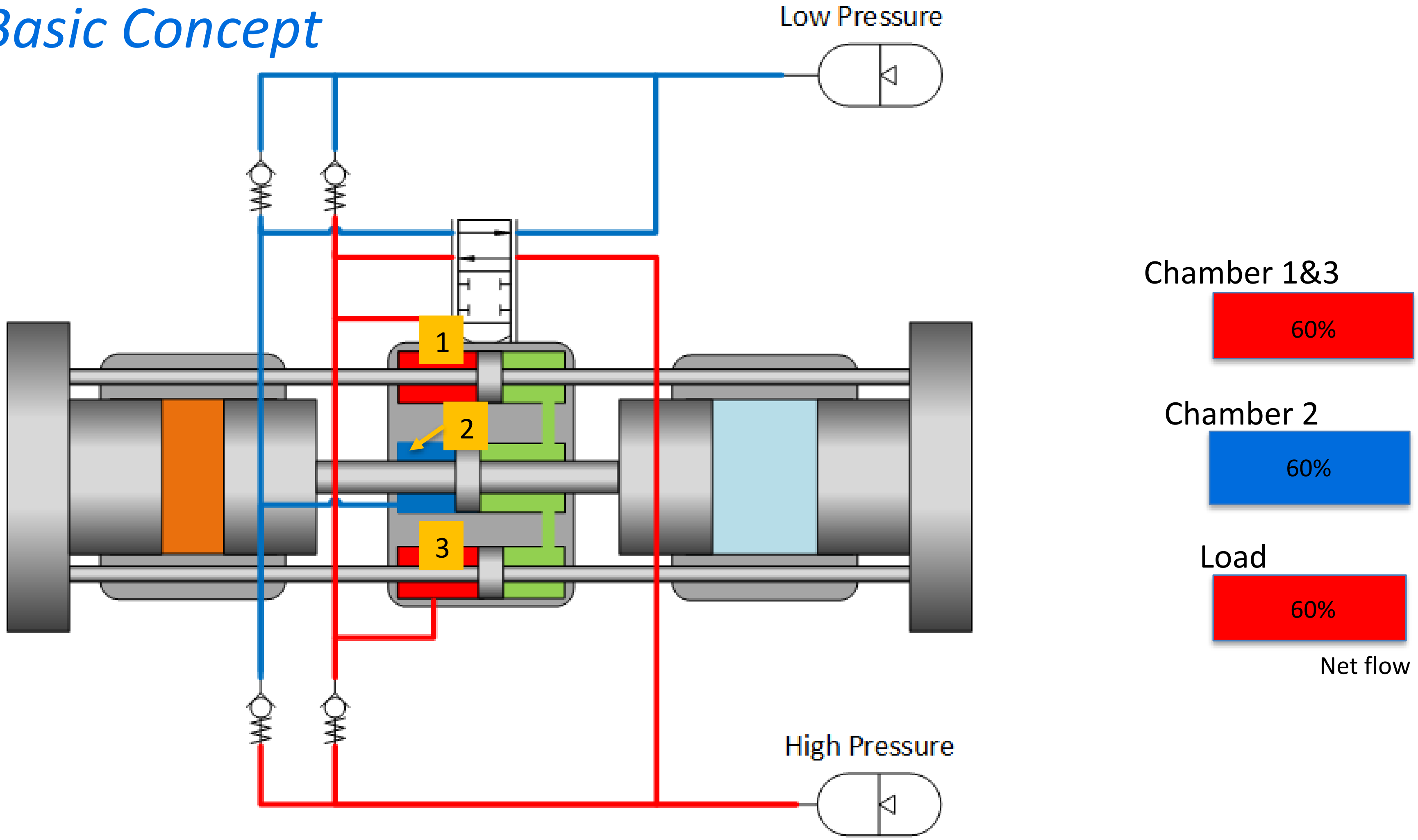

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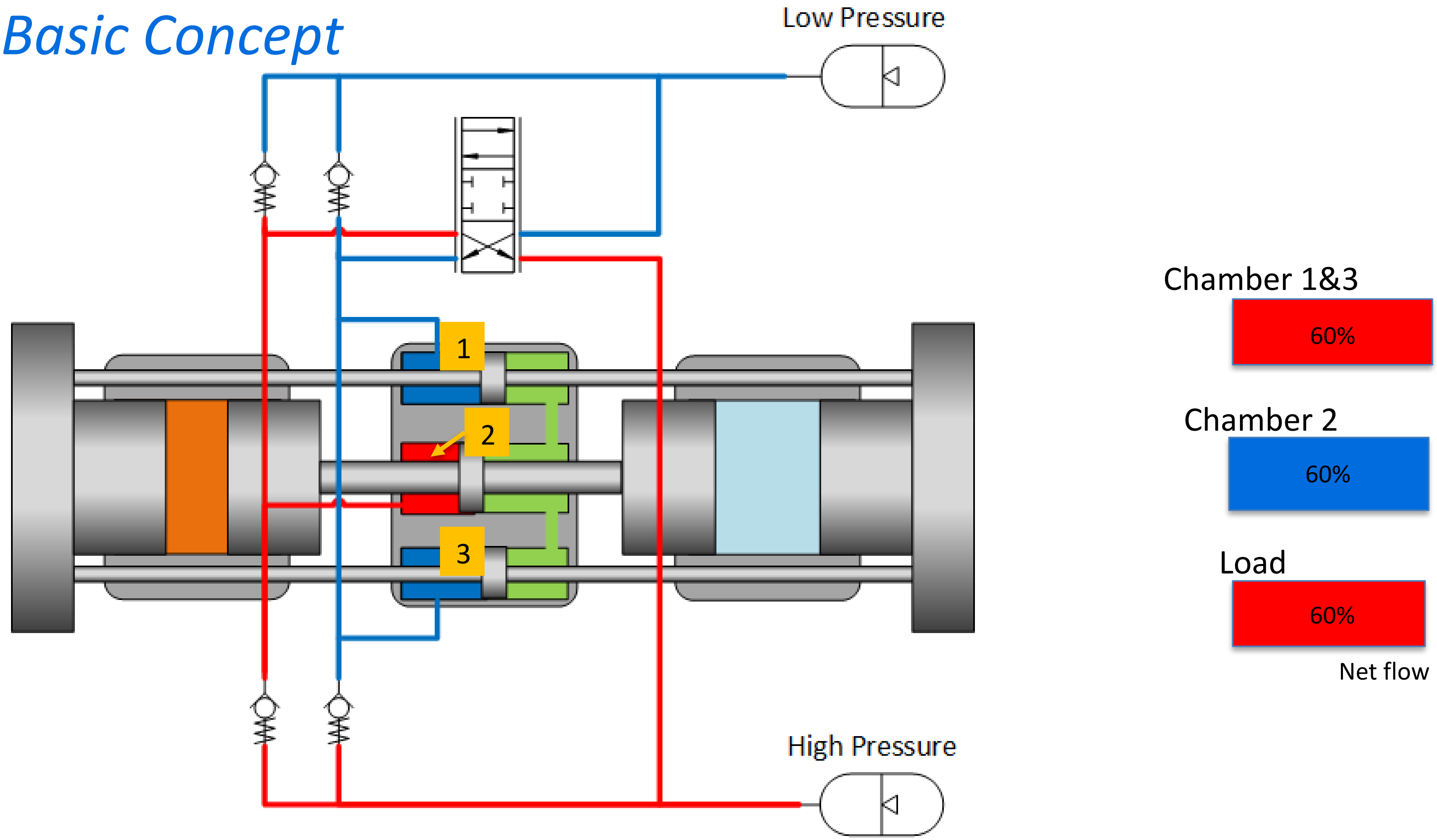

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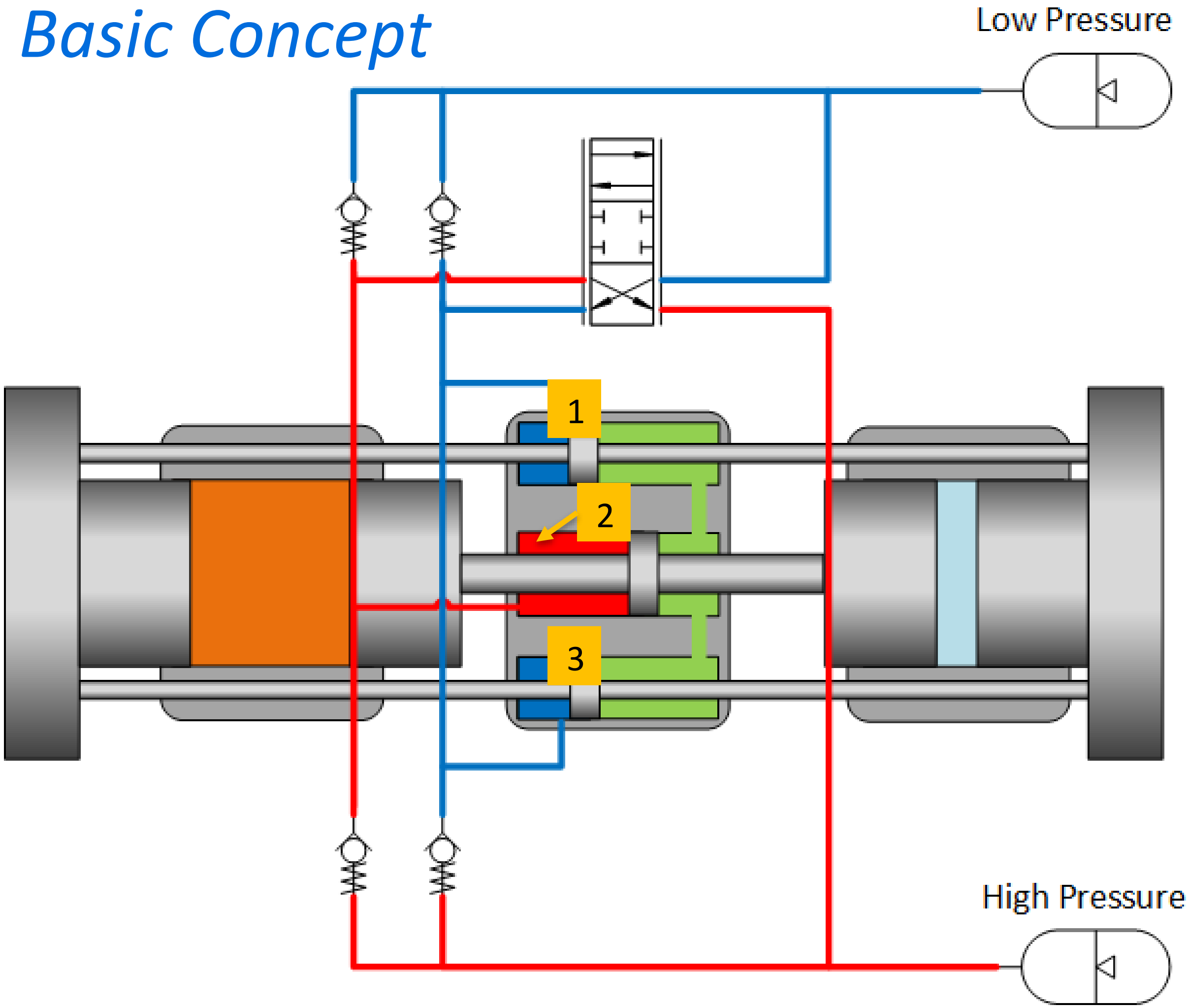
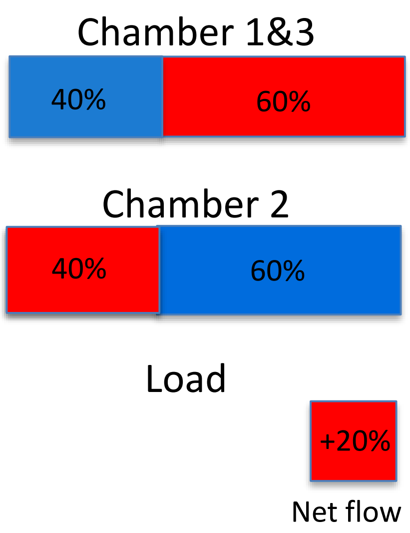
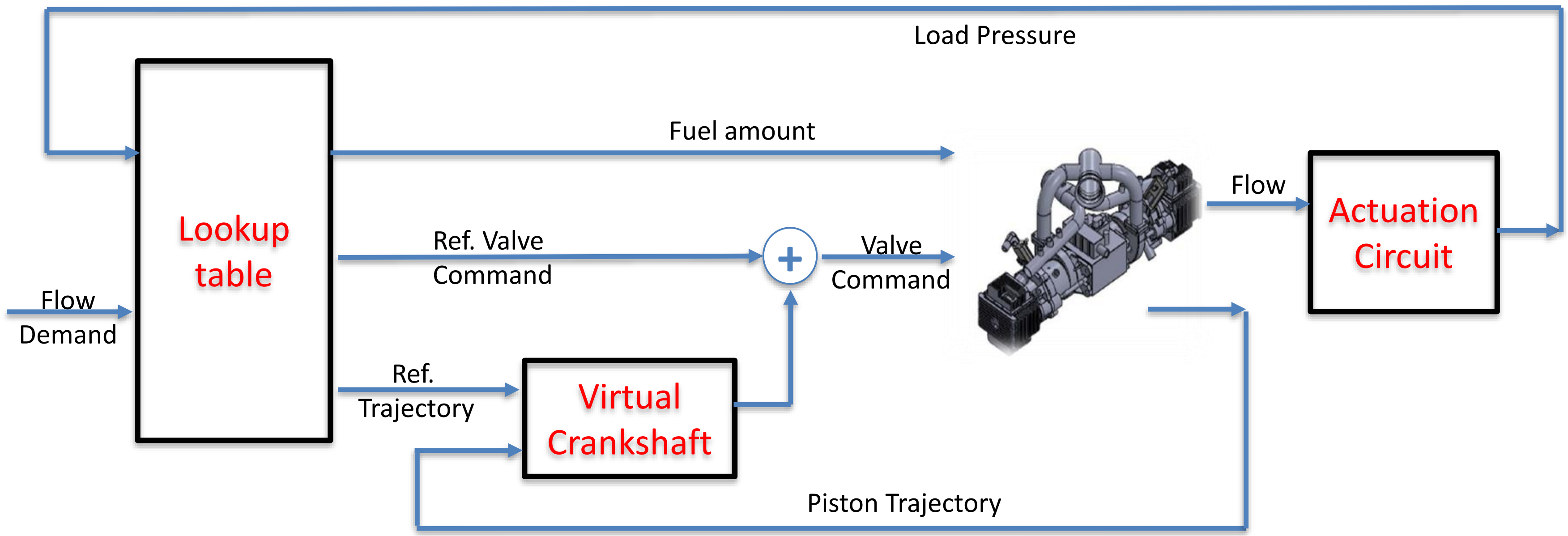


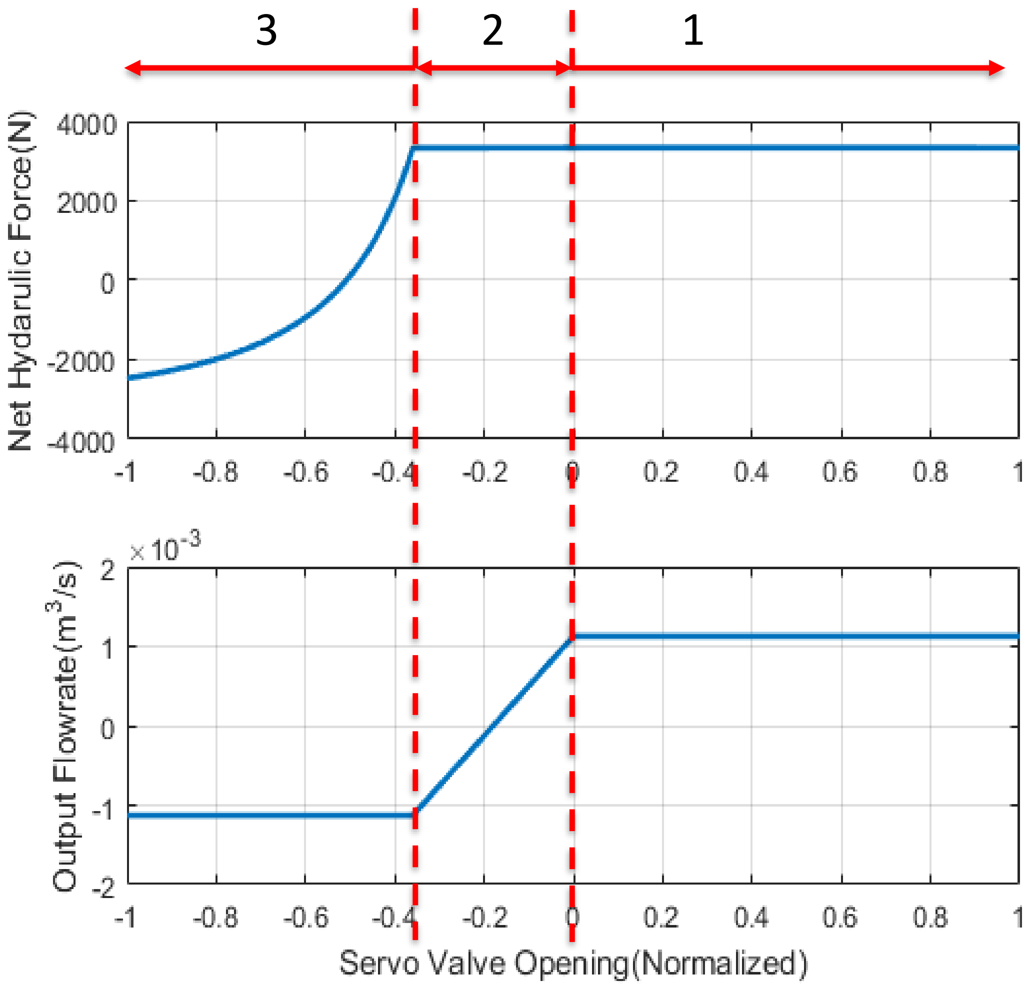


Independent Pressure and Flow Rate Control

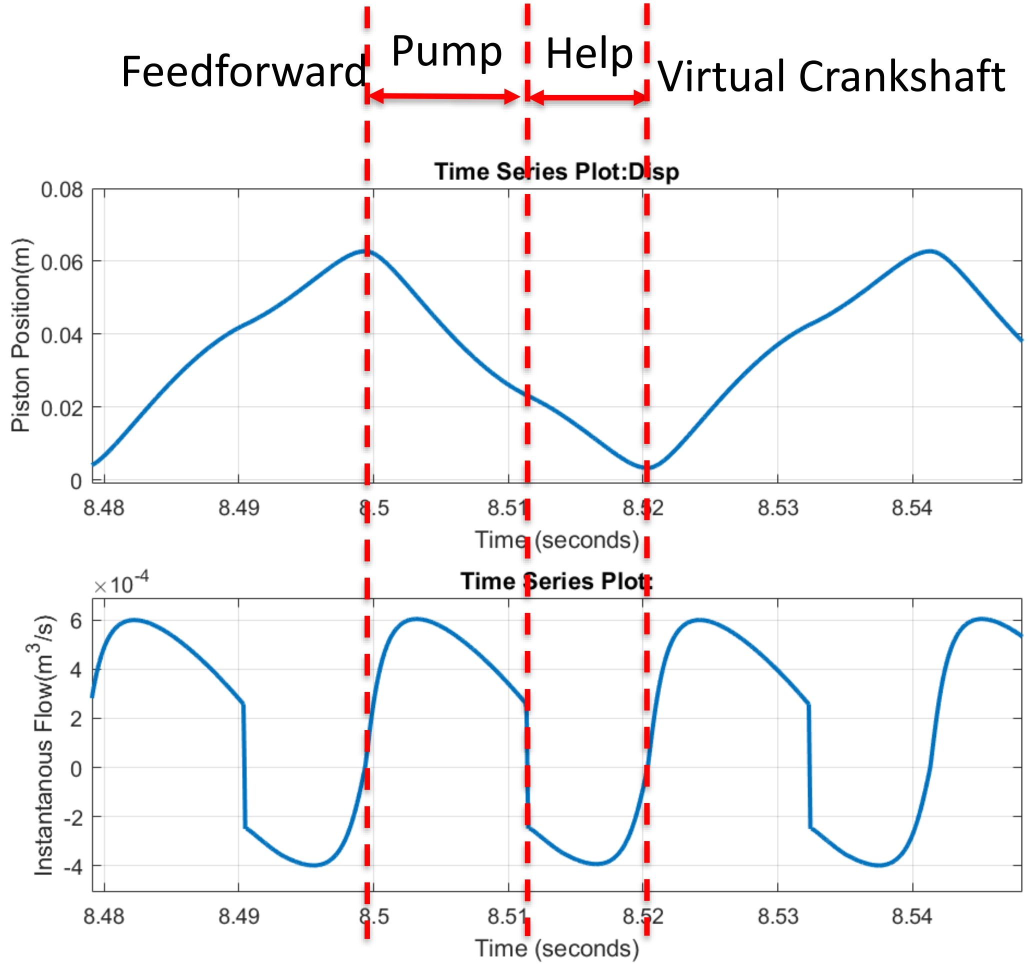
Realization: General Structure



- The virtual crankshaft is incorporated into the architecture
- Depending on the measured load pressure and flow demand, the feedforward controller gives the fuel amount, reference valve command and reference trajectory
- The virtual crankshaft regulate the valve signal to track the reference trajectory



- Feedforward on pumping part; virtual crankshaft on dumping part
- Nominal working point @ 80% servo valve opening
- Virtual crankshaft regulate opening around this point



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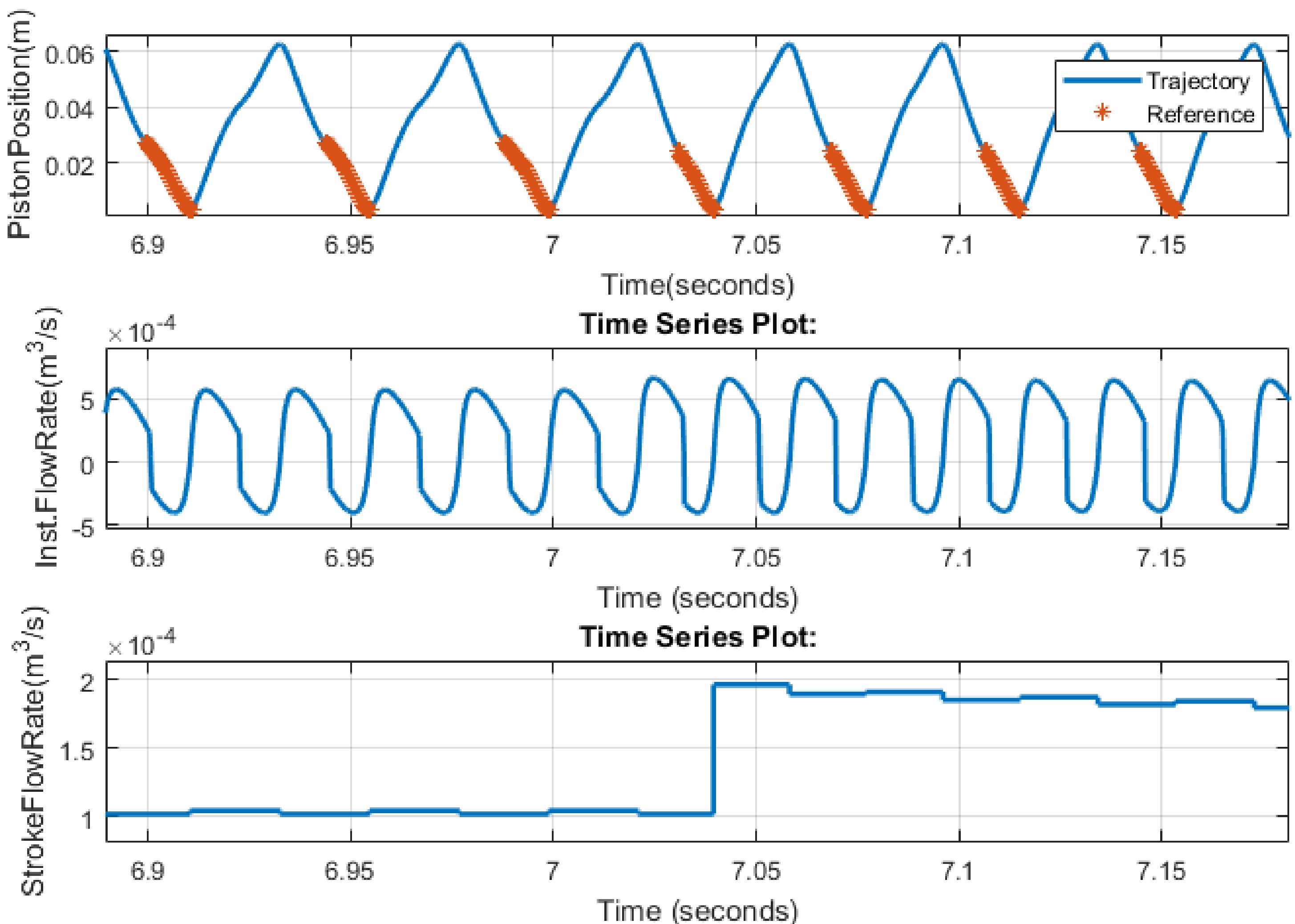
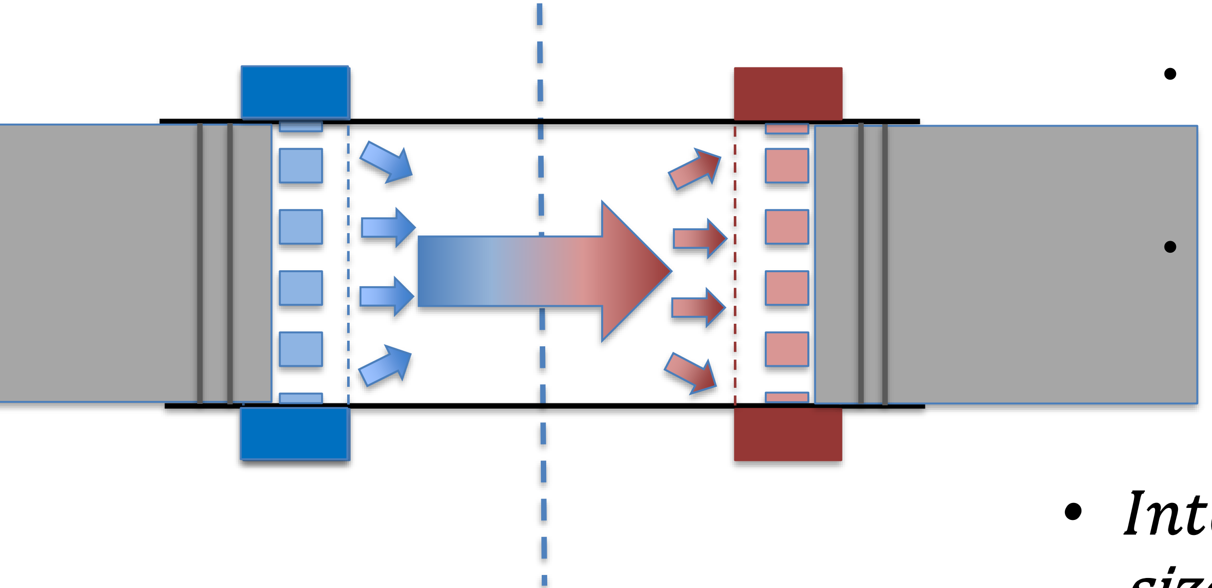
Robust Realization: Transient



Pressure: 4000psi

Consecutive Combustion Tests

Improvement of scavenging



- Fresh charge sweeps through the chamber
- Port opening is coupled with piston motion

- $IntakeAmount = f(Port\ size, \textcolor{red}{intake\ pressure}, port\ open\ order, open\ duration, chamber\ pressure)$

Consecutive Combustion Tests

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Consecutive Combustion Tests

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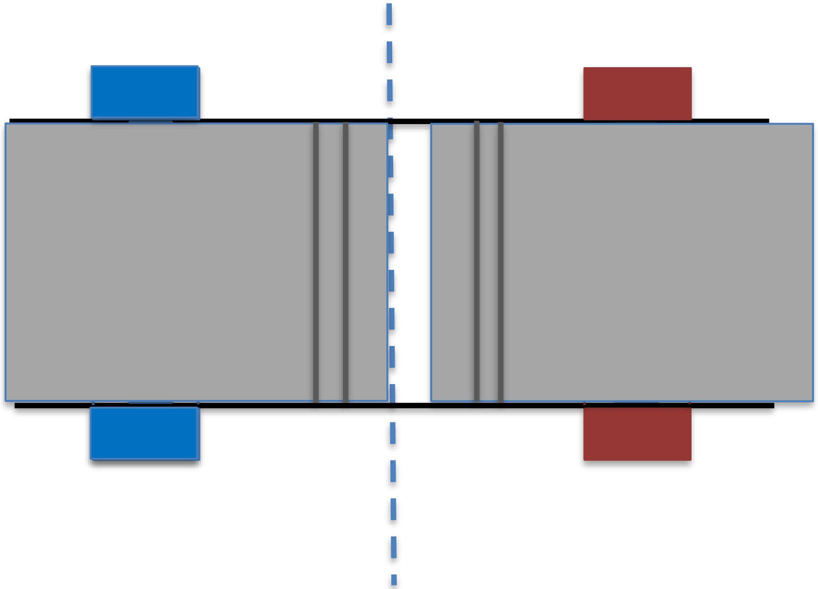
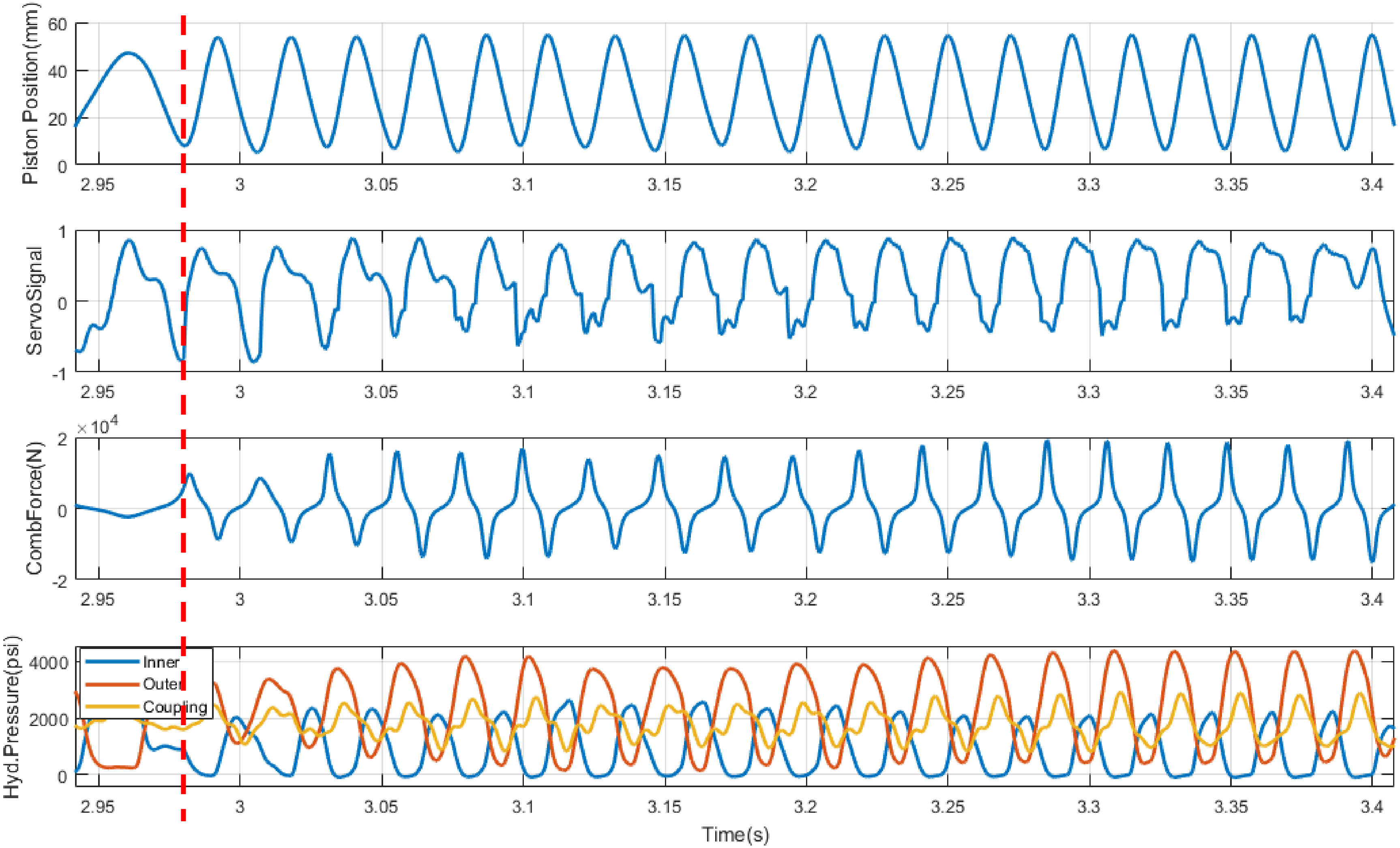


- Fresh charge sweeps through the chamber
- Port opening is coupled with piston motion

- *IntakeAmount = f(Port size, intake pressure, port open order, open duration, chamber pressure)*

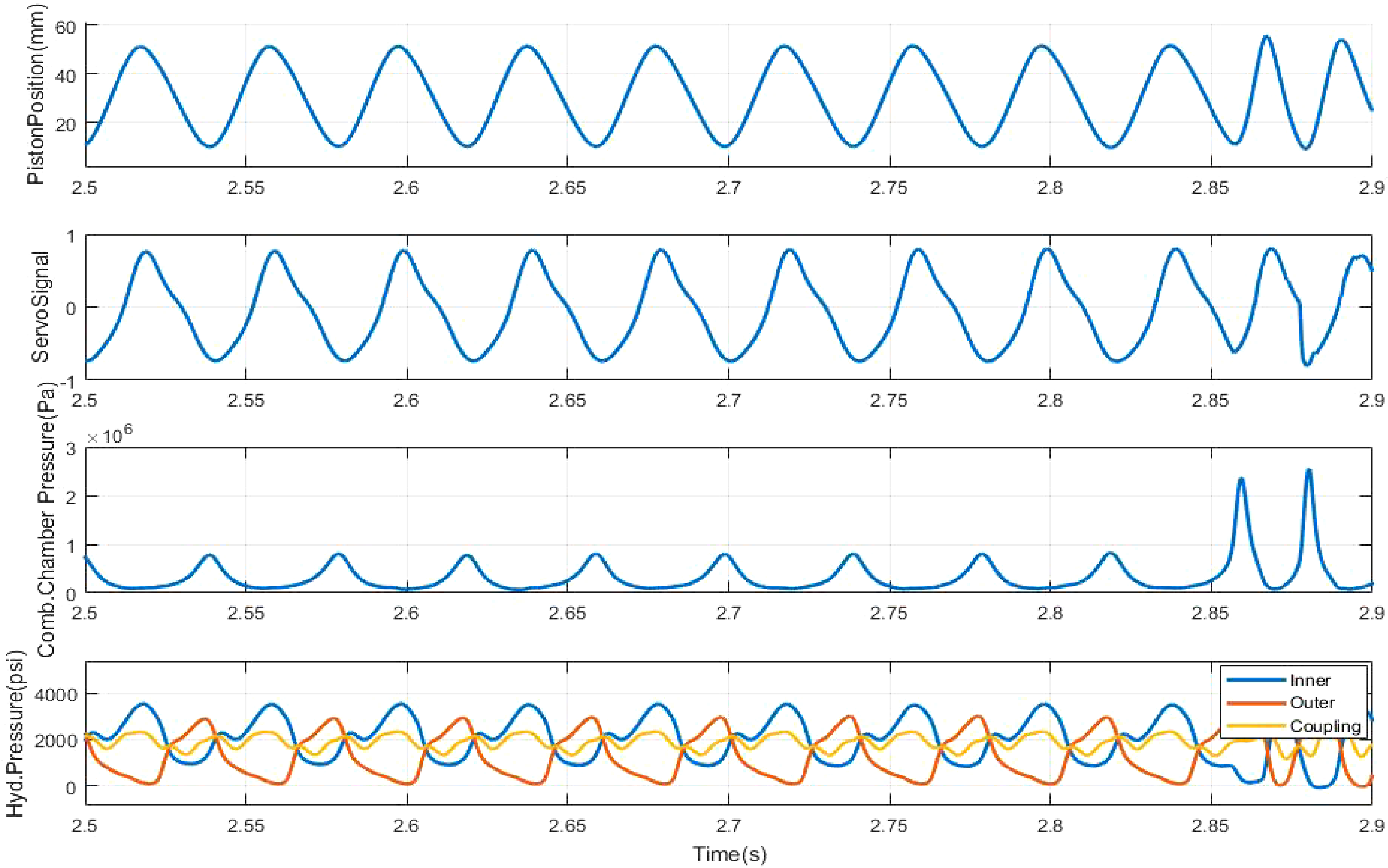
Consecutive Combustion Tests

Consecutive combustions



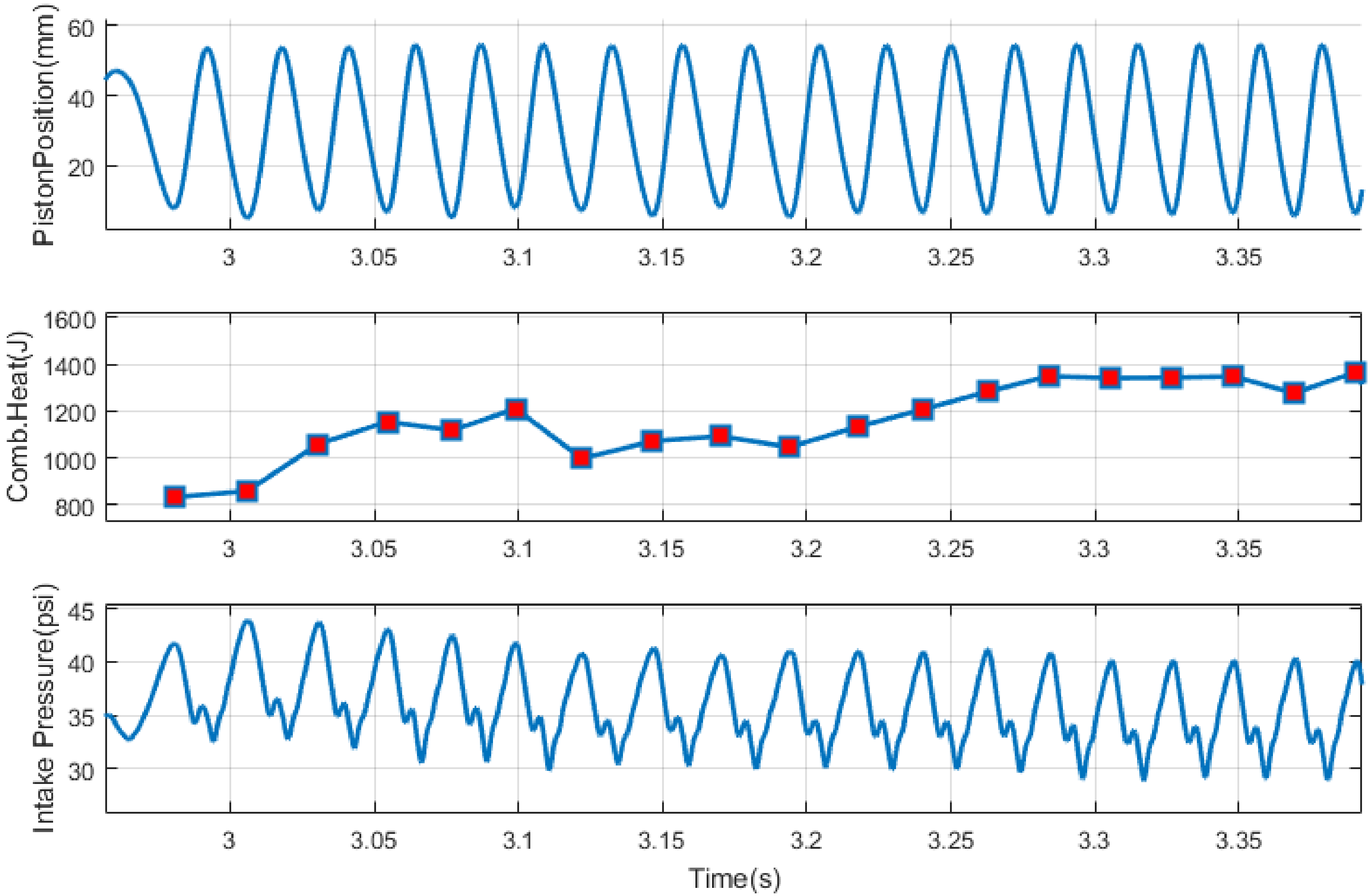
Consecutive Combustion Tests

From motoring to combustion



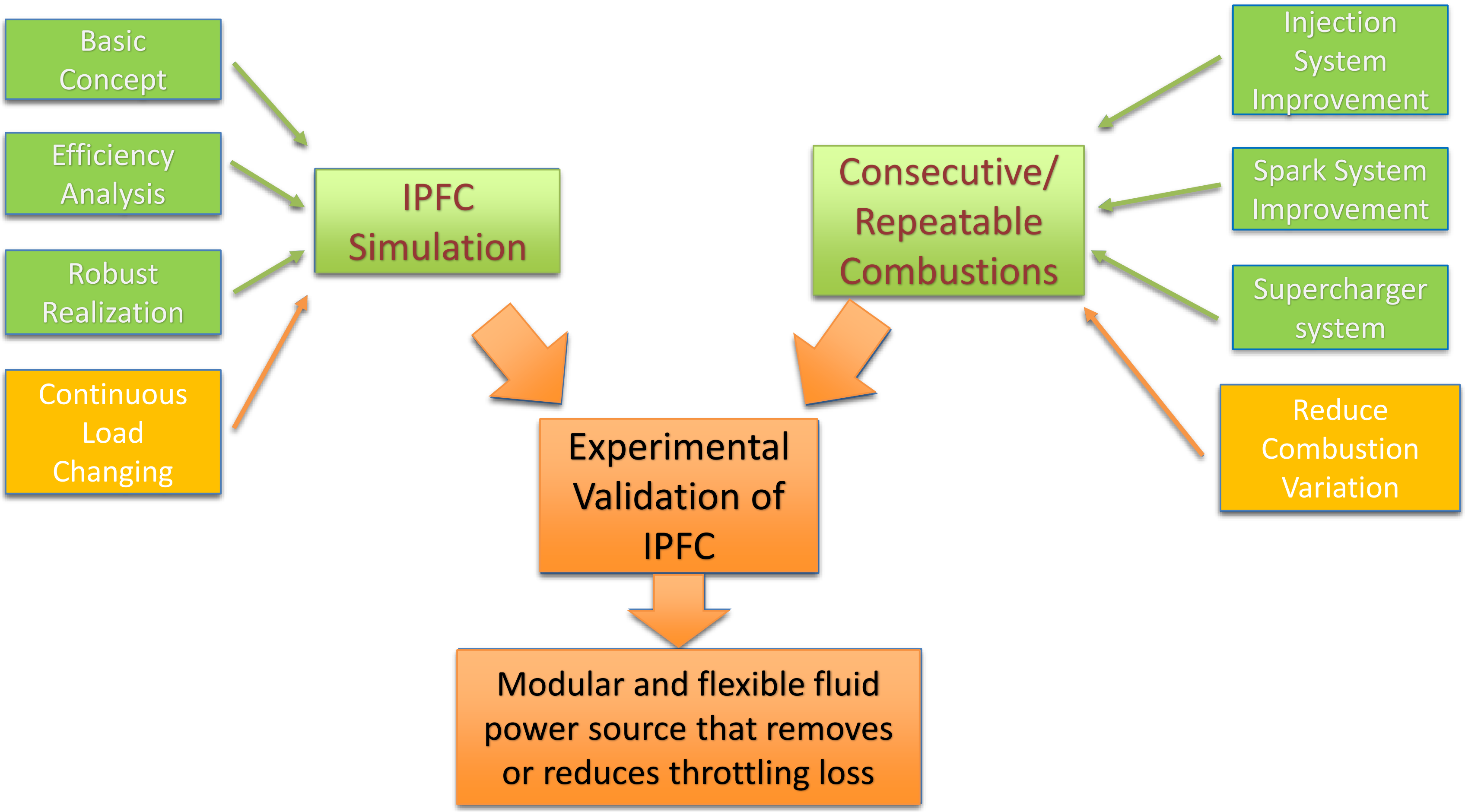
Consecutive Combustion Tests

Combustion heat release



Consecutive Combustion Tests

Foundation for experimental validation



Summary and future work

- Simulation results shows that with proper control of valve command and fuel injection, the FPE can work as a digital fluid power source with very short response time.

- Efficiency analysis shows that the optimal working conditions can be found and the overall system efficiency is higher than the current solutions.

- With the supercharger system and optimized piston motion/port order, scavenging process is improved and consecutive/repeatable combustion is realized.

- Experimental validation of IPFC will be conducted by implementing the proposed control strategy on the test bed.