Free-Piston Engine

Peter Van Blarigan
Sandia National Laboratories

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ACE08, Salon E&F, 1:45 – 2:15 PM, Tuesday, May 19, 2009

Sponsor: DOE Office of Vehicle Technologies
Program Managers: Gurpreet Singh and Kevin Stork

Project ID: ace_08_vanblarigan

Overview

Timeline

- Start – 1995
- Project provides fundamental research that supports DOE/ industry advanced engine development projects.
- Project directions and continuation are evaluated annually.

Budget

- Project funded by DOE
- FY08: $300K (CPS 10055)
- FY09: $100K (CPS 10055) and $400K (CPS 13418)

Barriers

- Increased thermal efficiency via high compression ratios
- Multi-fuel capability via variable compression ratios – hydrogen, ethanol, biofuels, natural gas, propane, etc.
- Lean, premixed combustion for low emissions – LTC and HCCI
- Low cost and mechanical simplicity – port fuel injection, uniflow port scavenging

Partners

- Ronald Moses (LANL)
- General Motors/University of Michigan
- Stanford University

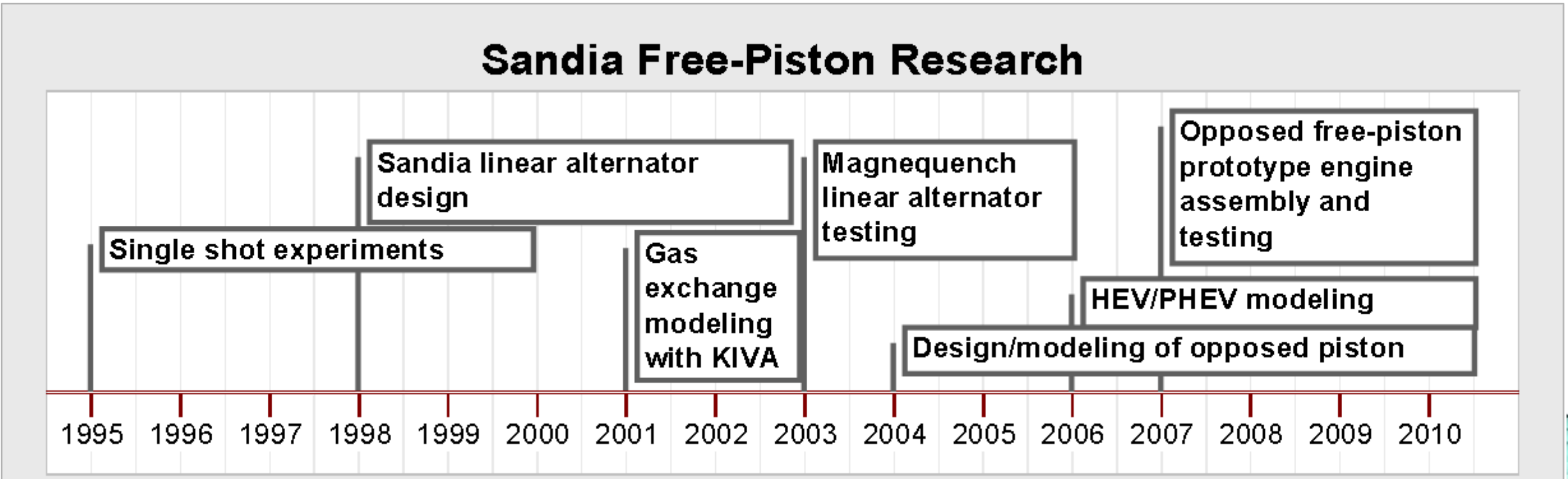
Objectives

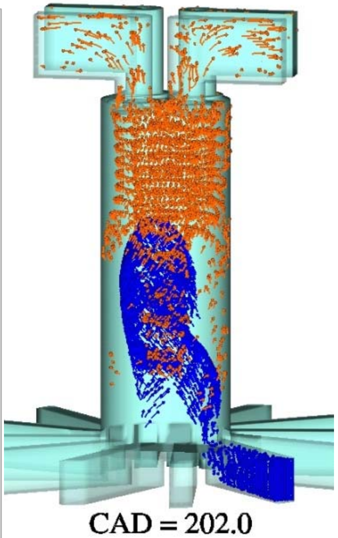
Goals of the Free-Piston Engine Research Prototype

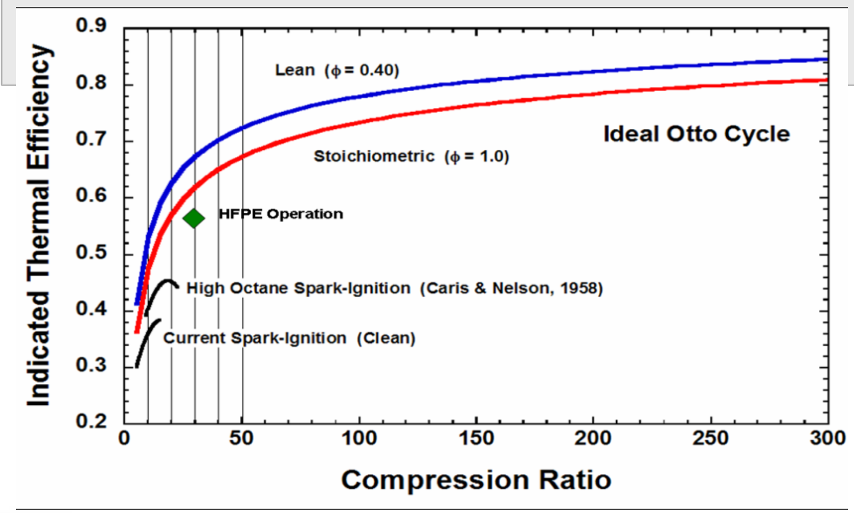
- To study the effects of continuous operation (i.e. gas exchange) on indicated thermal efficiency and emissions at high compression ratios (~20-40:1)
- Concept validation of passively coupling the opposed free pistons via the linear alternators connected to a common load to maintain piston synchronization
- Proof of principle of electronic variable compression ratio control

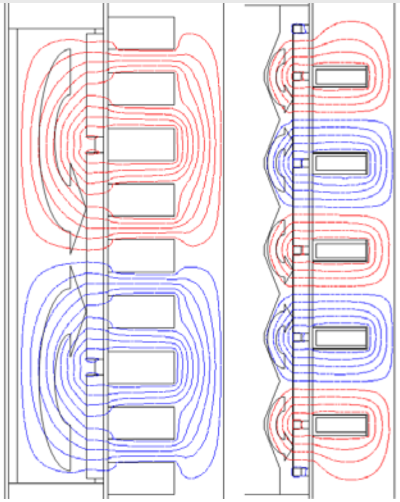
Milestones

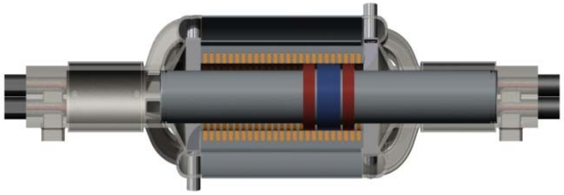
Using a combination of subsystem experiments and modeling, build and test a full-scale research prototype to demonstrate high efficiency and low emissions.







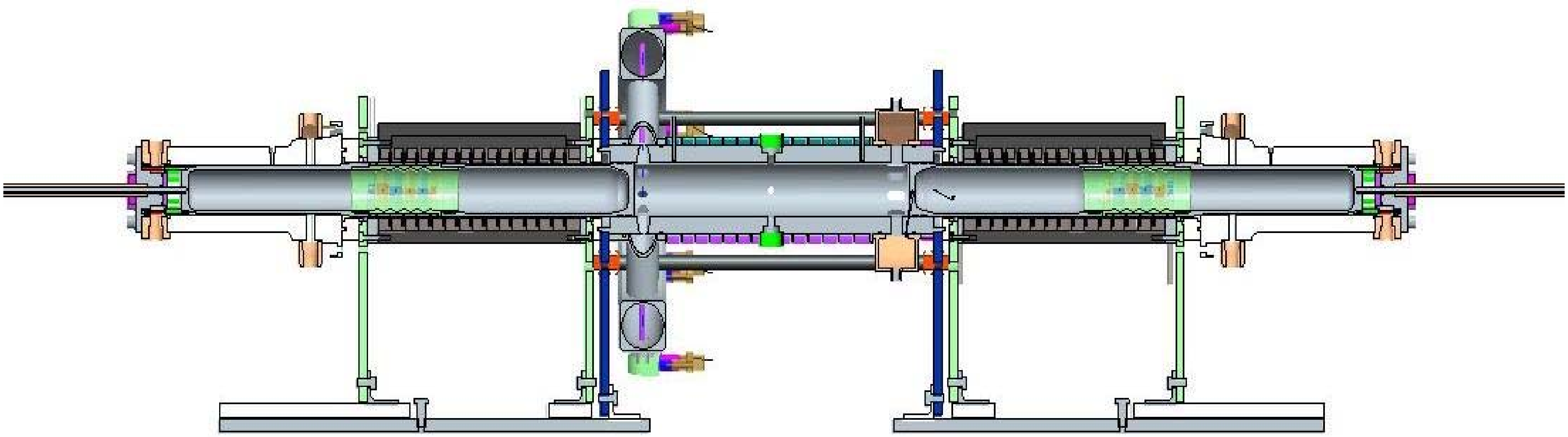




Approach - Prototype

Design of a continuously operating, opposed free-piston engine

- Compression ratio variable from ~20:1 to 40:1
- Port fuel injection (gaseous and liquid injectors)
- Bore = 81.15mm, Stroke of each piston = 215-220mm
- Oscillation frequency = 23-28Hz (Mean piston speeds ~10-12m/s)
- Uniflow gas exchange with boosted intake capability for efficient scavenging
- Constant load via linear alternators (~15kW combined electrical output)



Approach - Stability

Opposed piston synchronization via passive coupling of the linear alternators to a common load

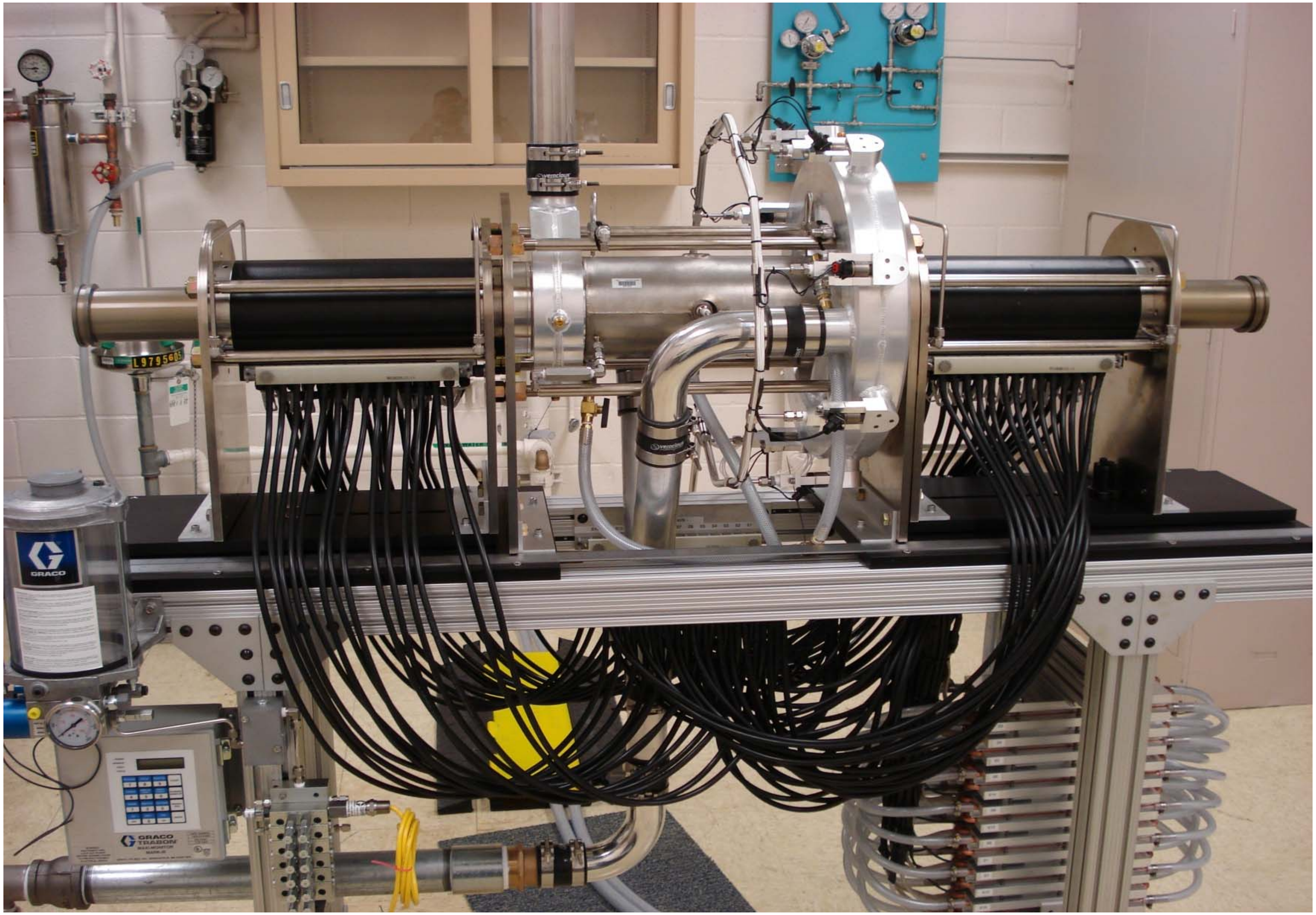
- Opposed piston configuration has two main benefits:
  - Inherent mechanical balance of overall engine when pistons are synchronized
  - Opportunity to utilize a central combustion chamber with highly efficient uniflow scavenging via intake and exhaust ports (no valves)
- Opposed piston synchronization is critical to both balance and gas exchange, as well as combustion and mechanical durability.
- Ronald Moses model: full simulation of piston dynamics, linear alternator electromagnetics, and load circuit; simplified energy input and friction; no detailed combustion kinetics, heat transfer, or gas exchange effects
- Model tracks piston synchronization stability for various loads.

Approach – Gas Dyno

Variable compression ratio control

- Require capability to test a range of compression ratios
- Desire capability to oscillate, or “motor”, pistons at required compression ratio without combustion but with constant electrical load to maintain stabilization force of coupled linear alternators
- Solution is to use high-pressure air injection into the bounce chambers at each end of the engine to start resonant piston motion and achieve desired compression ratio before introducing any fuel into the central combustion chamber.
- Compression ratio control during motoring is achieved by controlling both air injection into and vent pressure out of the bounce chambers.
- Load control when adding combustion energy at constant compression ratio is achieved by varying only vent pressure out of bounce chambers as fuel injection is increased, until full power is achieved via combustion only.

Technical Accomplishments – Prototype



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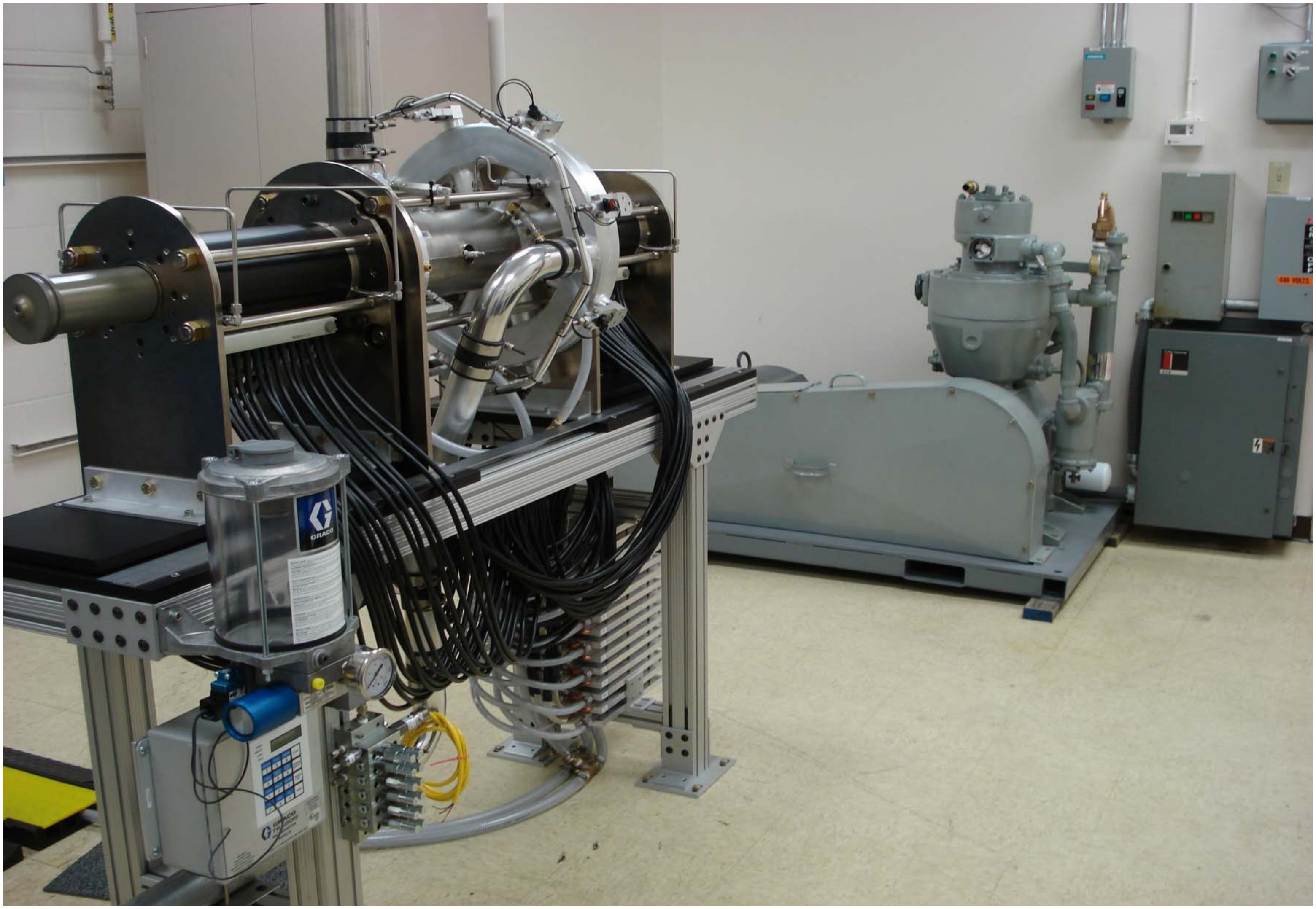
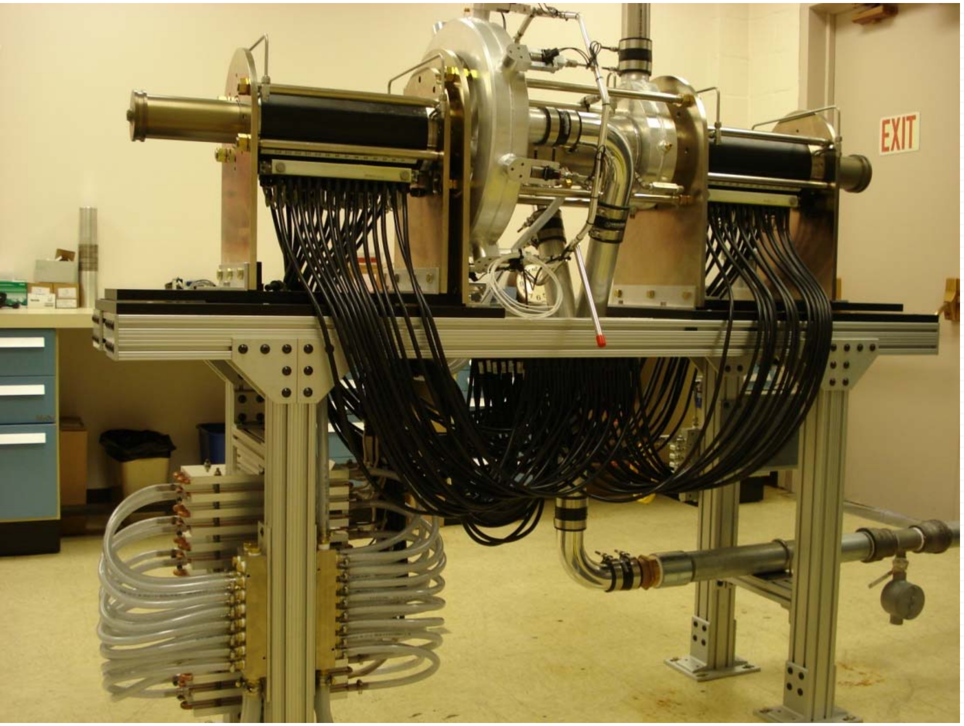
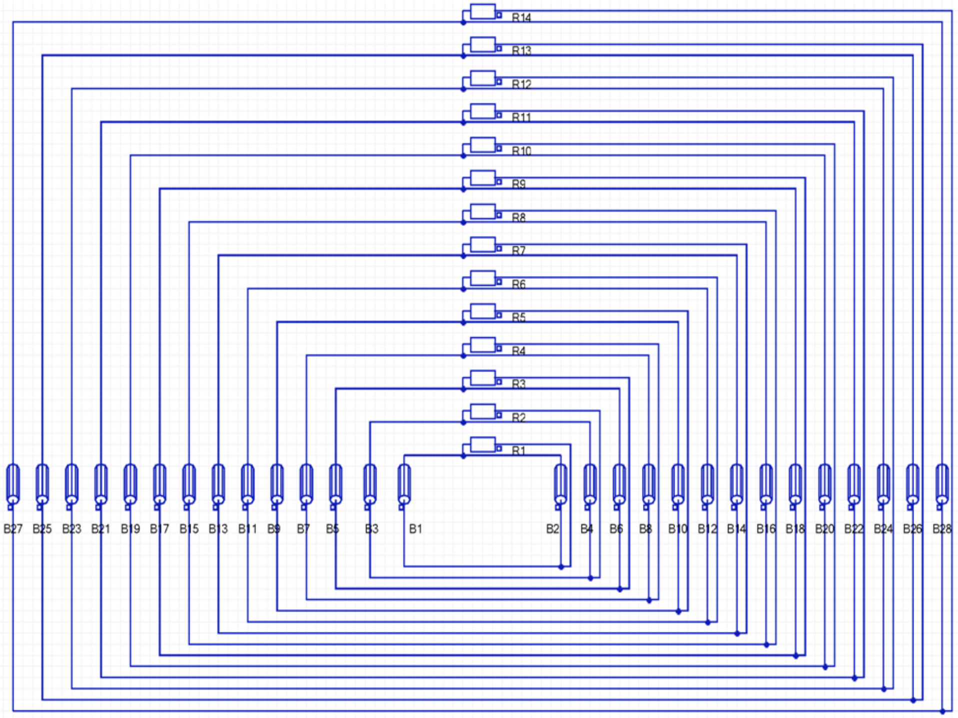


Technical Accomplishments – Stability

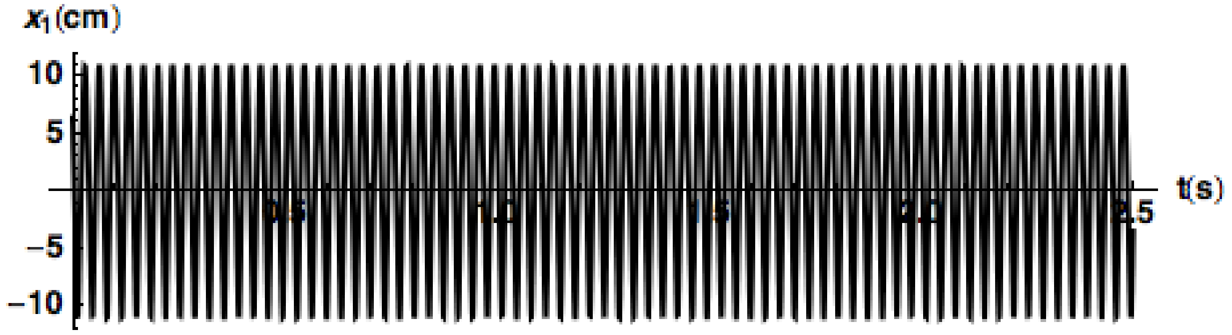




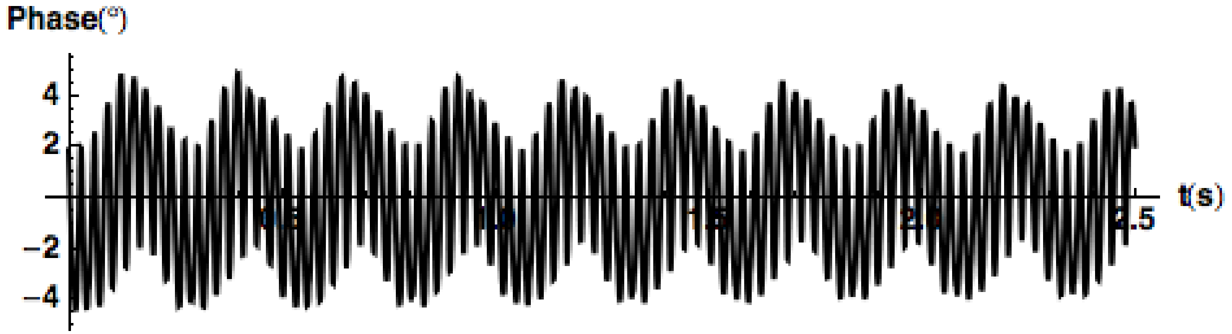
- Load circuit is designed to minimize internal resistive heating of the stator assemblies to reduce required cooling, yet still be effective in maintaining piston synchronization.
- Each coil is coupled in parallel with its respective coil from the other alternator to a single resistor of 0.182Ω. Each coil consists of 14 turns and has an internal resistance of 0.026Ω.

Technical Accomplishments – Stability

Position of Mover #1 over 72 cycles

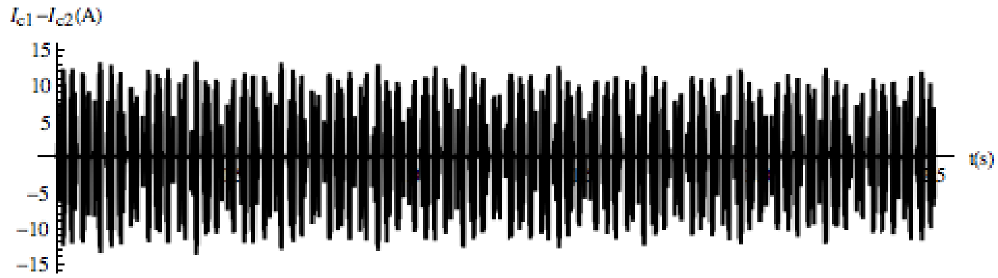


Relative phase of two movers in degrees, per coil pair cycle (1 tooth of linear alternator = 180 of phase)

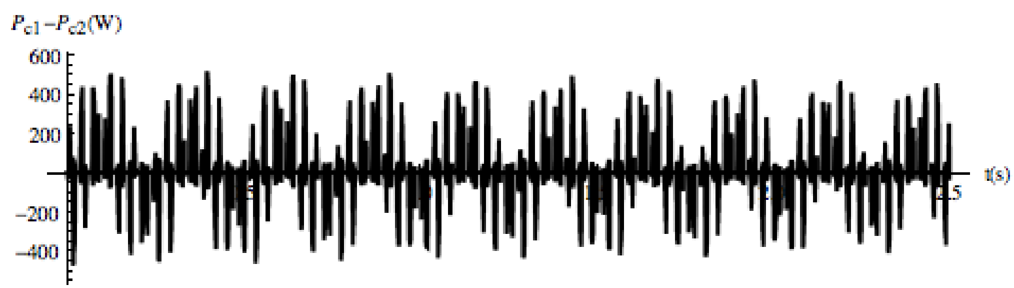


Technical Accomplishments – Stability

Current difference between seventh coil on set 1 and seventh coil on set 2 shows widely fluctuating values.



Corresponding electric power difference oscillates with the phase difference at ~14% of the engine frequency. This is the mechanism by which the phases are bound in cyclic motion.



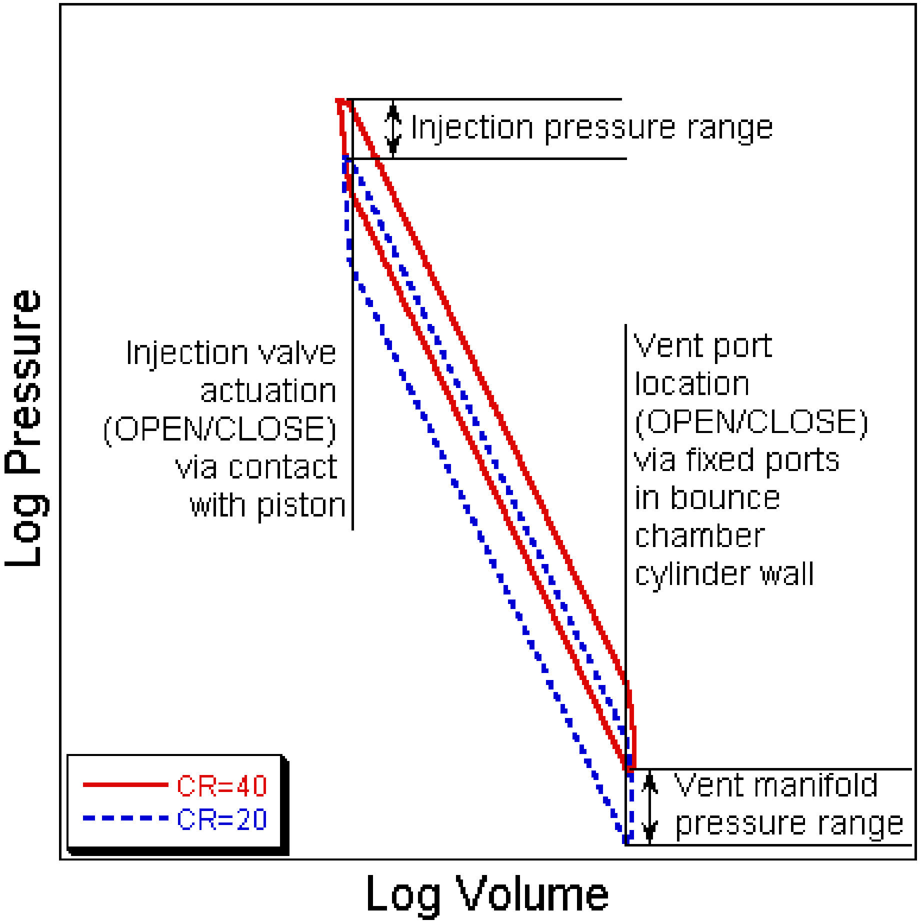
On average, Mover #2 expends 18 more Watts in friction than Mover #1, while Mover #1 produces 51 more Watts electric power than Mover #2.

Technical Accomplishments – Gas Dyno

Variable compression ratio - motoring

- Compression ratio can be varied from ~20:1 up to ~40:1 by increasing both bounce chamber air injection pressure and bounce chamber vent pressure.
- Oscillation frequency at 20:1 is ~23Hz and at 40:1 is ~28Hz.
- This boosting method gives nearly identical piston travel and air injection valve displacements.
- Desired geometric and effective compression ratios are maintained.

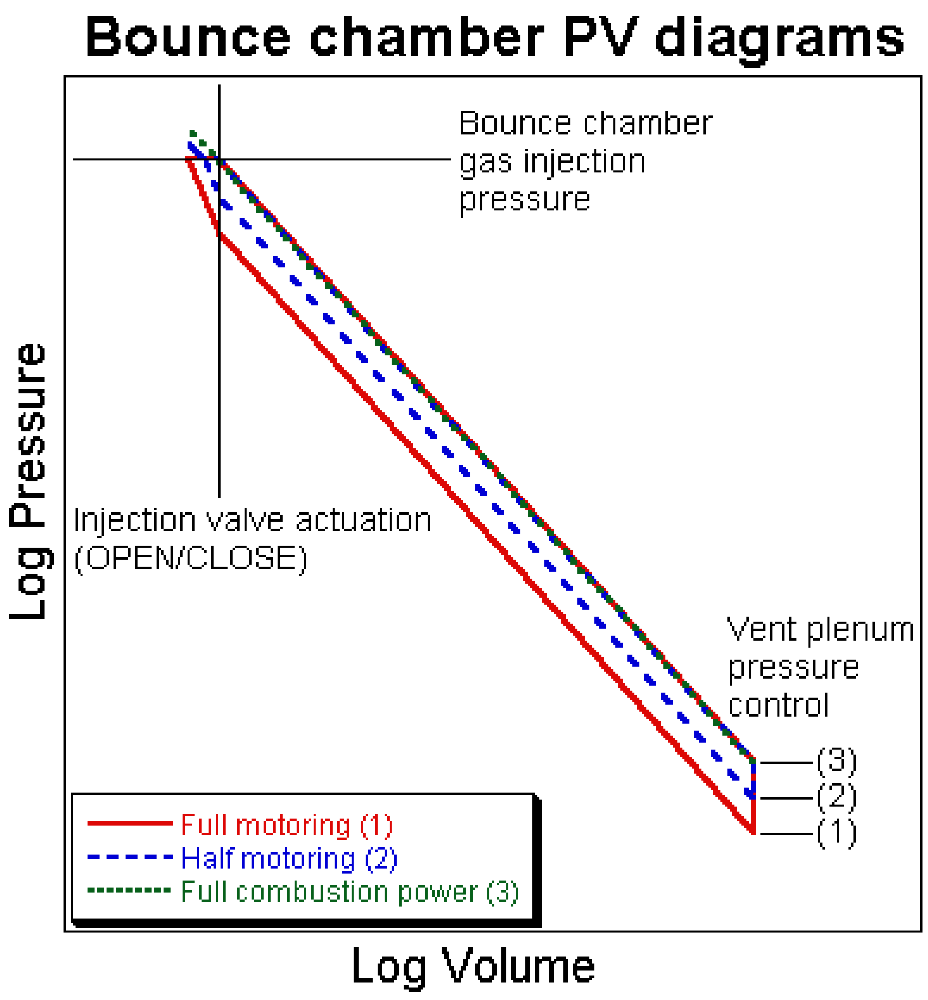
Bounce chamber PV diagrams



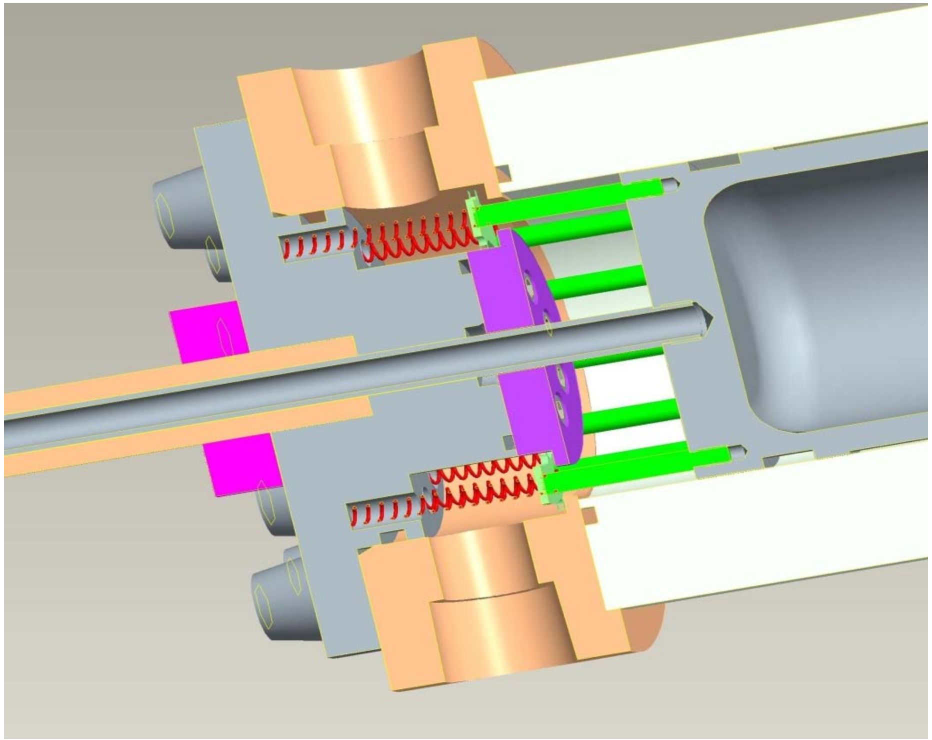
Technical Accomplishments – Gas Dyno

Bounce chamber air injection - combustion

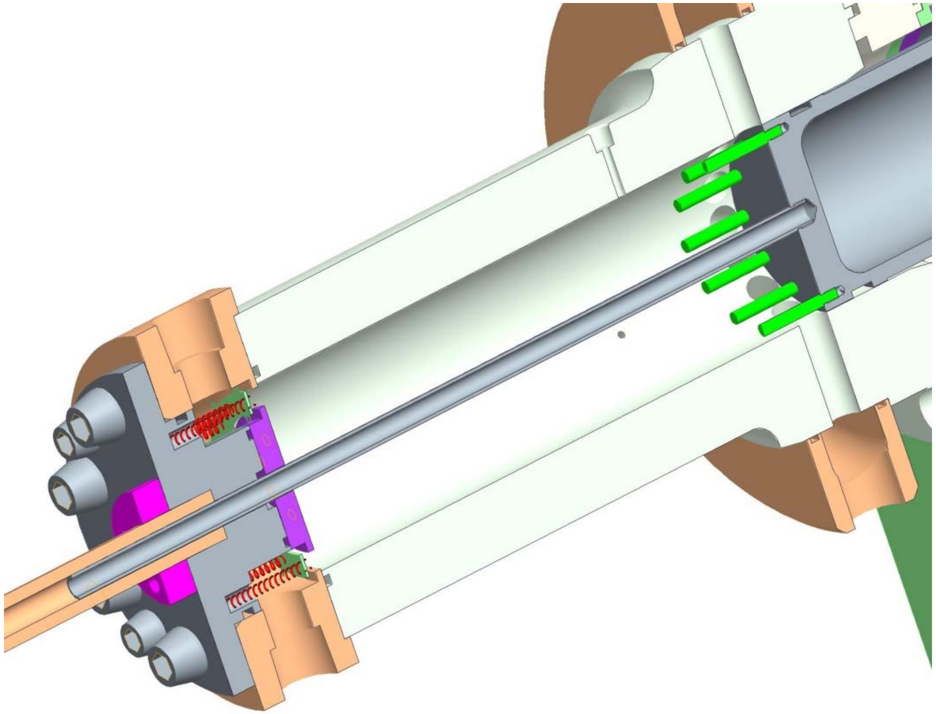
- Desired compression ratio achieved with no energy input via combustion.
- Injection valve is actuated by piston contact.
- When fuel injection begins and combustion is achieved, the bounce chamber vent pressure is increased, forcing more air to remain in chamber and reducing required amount of air injection.



Technical Accomplishments – Gas Dyno



Detail of bounce chamber air injection valve, showing piston actuation.



Overview of bounce chamber design, showing injection valve at the left and vent ports to the right.

Future Work

- **Complete research prototype and gas dyno fabrication**
  - Bounce chamber injection valve and cylinder
  - Gas dyno air supply, piping, tanks, controllers
- **Initially run the engine under air injection motoring mode only to test the stabilizing capability of the linear alternator coupling**
- **Perform combustion experiments at various compression ratios and equivalence ratios with both conventional and alternative fuels**

Hydrogen	**Ethanol**
Natural Gas	**Biofuels**
Propane	**Renewables**
Gasoline	

Summary

- Free-Piston Engine Research Prototype design and fabrication nearly complete.
- Stability modeling of prototype load circuit shows adequate power output and piston synchronization.
- Gas dyno concept developed to achieve desired resonant piston motion and test linear alternator coupling before combustion is initiated.
- Collaboration with partners on modeling of prototype engine and alternator design is ongoing.
- Program on track to start experimental testing in Spring/Summer 2009.