Stoichiometric Compression Ignition (SCI) Engine Concept

DOE Contract DE-FC26-05NT42416

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Outline

History
Objectives
Overall Concept
Major Issues
Comparison to Other Concepts
Status of Development
Further Work
Acknowledgements
Operation of Diesel Engines at Stoichiometric

Starting

Full load at low speeds

Military Investigations in 1989 – 1991 for increased power

Full time Stoichiometric Compression Ignition for emission control on DDC Series 60 prototype engine in November, 1981
Program Objectives

• Heavy-duty vehicle engine of reasonable size and cost
• Engine meeting 2010 on-highway emission standards
• Superior fuel economy and life cycle cost
• Applicability to off-highway vehicles
SCI Concept

- Operate compression ignition engine at stoichiometric and use three-way catalyst for control of NOx, HC, and CO
- Use continuously-regenerating diesel particulate filter for PM control
- Obtain superior fuel efficiency because of rapid combustion near TDC and efficient air system with reduced exhaust aftertreatment losses
Major SCI Issues

• Smoke and PM at $\phi = 1.00$
• NOx level and three-way catalyst efficiency
• High exhaust temperature
• Control to maintain stoichiometry, especially during rapid load changes
• Transient response
Comparison of Alternative Combustion Concepts

- Massive EGR – high percentages of EGR at relatively rich A/F ratio to reduce NOx
- Extreme EGR – very high EGR to give true Low Temperature Combustion (LTC) with low NOx and PM
- HCCI – homogeneous charge ignites and produces very little NOx and PM (requires EGR for higher loads)
- PPCI – some homogeneous charge ignites near TDC, while remainder of fuel is injected relatively late to minimize NOx
- SCI – conventional diesel combustion at near optimum timing with $\phi = 1$
## Full Load Estimates of Low Emission Concepts

<table>
<thead>
<tr>
<th>Combustion System</th>
<th>% EGR</th>
<th>$\phi$</th>
<th>Major Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive EGR</td>
<td>40 - 50</td>
<td>0.8</td>
<td>power &amp; PM</td>
</tr>
<tr>
<td>Extreme EGR</td>
<td>60 - 70</td>
<td>0.9</td>
<td>power &amp; efficiency</td>
</tr>
<tr>
<td>HCCI</td>
<td>45 - 55</td>
<td>0.9</td>
<td>power &amp; control</td>
</tr>
<tr>
<td>PPCI</td>
<td>40 - 50</td>
<td>0.8</td>
<td>control and PM</td>
</tr>
<tr>
<td>SCI</td>
<td>0 - 20</td>
<td>1.0</td>
<td>control, NOx &amp; PM</td>
</tr>
</tbody>
</table>
Advantages of SCI Concept

- Little or no EGR
- High power capability with moderate cylinder pressure
- Low air and exhaust flows
- Low turbocharger boost requirements
- Rapid combustion near TDC for good fuel economy
- Easy starting and reliable combustion
- Relatively simple and reliable exhaust aftertreatment
Base Engine – John Deere 6090

9L six-cylinder
242 kW @ 2100 rpm
1530 N-m @ 1575 rpm
118.4 x 136 mm bore x stroke
Four-valve head with pushrods
Vertical central common rail injector
Single-piece steel piston
Variable geometry turbocharger
Air-to-air intercooled
HPL cooled EGR
John Deere ECU
Off-highway Tier 3 compliant
Development Status

• Operated at stoichiometric at half and full load

• Smoke and PM – need improvement

• NOx – unclear

• BSFC - promising
Promising Early Results at Half Load

Stoichiometric Operation with some EGR

PM - g/kWh

NOx - g/kWh

Engine Speed - rpm

PM

NOx
Full Load Smoke Results (~ 20% EGR)

**Rated Power**

- Smoke - FSN
  - 712
  - 716
  - 812

**Peak Torque**

- Smoke - FSN
  - 712
  - 716
  - 812
Full Load NOx Results (~ 20% EGR)

Rated Power

Peak Torque
Methods to Reduce Smoke and PM

- Combustion system optimization
- Higher injection pressure
- Multiple injection strategy
- Less EGR – no EGR
- Higher H/C ratio in fuel
- Oxygenated fuel
BSFC Estimates from Simulation

- Simulation was baselined using production engine
- Heat release changed to curve calculated from cylinder pressure data at stoichiometric conditions
- With exhaust aftertreatment and using standard restrictions and efficiencies calculated 41% brake thermal efficiency at rated power and 42% at peak torque
- Air system restrictions and efficiencies are being reviewed for improvement based on the reduced flows and pressure ratios
- Camshaft is being optimized for the operating conditions
- Combustion is being improved by better mixing
Temperature – -15°

2500 K
1400 K
Studying Injection, Piston Bowl, and Mixing

Mixture Fraction – -15°
Likely SCI Engine Configuration

- Three-way Catalyst – for NOx control
- Low Boost Variable Geometry Turbocharger
- Variable Valve Actuation - for load control
- Diesel Particulate Filter with air injection – for PM control
- No EGR – for simplicity, cost, low heat rejection
- High Injection Pressure – for PM control
Next Development Activities

• Demonstrate acceptable engine-out smoke and PM
• Refine fuel consumption estimates
• Develop F/A ratio control for three-way catalyst
• Install VVA system for load control in conjunction with VTG
• Consider higher power for better brake efficiency (thermal loading issues)
Acknowledgements

- John Fairbanks - DOE Technology Development Manager
- Ralph Nine - DOE Project Manager
- Ricardo Inc. for air system simulations using WAVE
- Prof. John Abraham (Purdue University) for CFD of combustion system
- Sturman Industries for advanced injection system