Potential of CNG-Direct-Injection for Downsizing Engine Concepts

Thomas Hofherr, MSc

Institut für Fahrzeugeantriebe & Automobiltechnik
Content

- Motivation
- State of the Art - Natural gas engines
- Engine – Modifications
- Results
- Conclusion
Motivation – Natural Gas Direct Injection

- Knock resistance $\uparrow$

<table>
<thead>
<tr>
<th>Fuel</th>
<th>octane number [RON]</th>
<th>stoichiometric air mass [kgAir/kgFuel]</th>
<th>mixture heating value x10 (mixture aspirated) [MJ/m³]</th>
<th>mixture heating value x10 (air aspirated) [MJ/m³]</th>
<th>gCO₂/MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>NG</td>
<td>~130</td>
<td>17,2</td>
<td>31,7</td>
<td>34,9</td>
<td>54,8</td>
</tr>
<tr>
<td>Gas</td>
<td>95</td>
<td>14,2</td>
<td>35,9</td>
<td>36,5</td>
<td>73,5</td>
</tr>
</tbody>
</table>

-25%
State of the Art – Natural Gas Engines

- Port Fuel Injection (PFI) – State of the Art
  - Displacement of air at WOT
  - Reduction of LowEnd Torque
  - Limited scavenging capabilities
  - Limited in catalyst heating strategies

- New approach: CNG direct injection
  - No displacement of air at WOT
  - High scavenging capabilities
  - High LowEnd Torque
  - Postinjection for catalyst heating

H.J. Neußer: Der neue Erdgasmotor von Volkswagen, MTZ 04/2013
# Engine Modifications

<table>
<thead>
<tr>
<th>Base Engine</th>
<th>Act. Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of cylinders</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Valves per cylinder</strong></td>
<td>4</td>
</tr>
<tr>
<td><strong>Valve train</strong></td>
<td>DOHC</td>
</tr>
<tr>
<td><strong>Displacement</strong></td>
<td>658 cm³</td>
</tr>
<tr>
<td><strong>Compression ratio</strong></td>
<td>8,8</td>
</tr>
<tr>
<td><strong>Fuel</strong></td>
<td>RON 95</td>
</tr>
<tr>
<td><strong>Mixture formation</strong></td>
<td>Gasoline DI</td>
</tr>
<tr>
<td><strong>Charging</strong></td>
<td>Turbo</td>
</tr>
</tbody>
</table>

Engine Modifications
Increasing the compression ratio – Combustion chamber shape

<table>
<thead>
<tr>
<th>Compression ratio $\varepsilon$ [-]</th>
<th>Surface / Volume ratio $[\text{cm}^{-1}]$</th>
<th>$\Delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.8</td>
<td>3.32</td>
<td></td>
</tr>
<tr>
<td>13.6</td>
<td>5.43</td>
<td>+64%</td>
</tr>
</tbody>
</table>

Exhaust valve
Intake valve
DI-Injector
Increasing compression ratio – Effects

Compression ratio of 12 is the optimum for this engine

Operating point: n = 2000 min⁻¹ BMEP= 4 bar

\[ \varepsilon = 8.8 \text{ Basis (CNG)} \]

\[ \varepsilon = 13.6 \]

\[ \varepsilon = 12.0 \]

- residual losses
- unburned losses
- wall heat losses
- efficiency (measured)

\[ \eta_{\text{th}} = 58.1\% \]

\[ \eta_{\text{th}} = 64.8\% \]

\[ \eta_{\text{th}} = 63.0\% \]
Operating Strategies for Direct Injection – WOT
Injection Timing

- In PFI engines A/F mixture is aspirated and air is displaced partially by fuel
- Direct injection engines aspirate pure air, fuel is injected after IVC

Injection after IVC gains 20% volumetric efficiency compared to intake-synchronous injection

Operating Strategies for Direct Injection – WOT combination

Late injection + scavenging double achievable torque
WOT – comparison different systems

Low End Torque of Gasoline can almost be achieved with CNG-DI @ high efficiency
Optimization – Results during the NEDC

-25% from CH₄

-33%

-8% from comb. process

-29%

Good compromise between high compression ratio and combustion chamber shape has to be found
Conclusion

- Development of an combustion process for CNG DI
- CNG allows significant raise in compression ratio
- Combustion chamber shape / wall heat losses / unburned losses limit the maximum compression ratio
- With CNG-DI the LowEnd Torque of gasoline is almost achievable
- Natural gas and optimized combustion process reach a reduction of CO₂ emissions of 33%
Thank you for your attention!

Thomas Hofherr, MSc
thomas.hofherr@ifa.tuwien.ac.at