Experiment study on HCCI combustion of a 4-cylinder OKP engine

Speaker: Li zhong zhao

Advisor: Prof Huang zhen

School of Mechanical & Power Engineering, Shanghai Jiao Tong University, Shanghai, People’s Republic of China

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Contents

• Research background
• Introduction of HCCI and OKP
• Experimental Setup
• Results
• Conclusions
Drivers for engine development

- More and more stringent emission regulations in all fields of application
- Limited resources and increasing demand require highly fuel efficient combustion engines
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Advantages:

• Higher thermal efficiency
• Lower exhaust pollution emission

Challenges:

• Ignition is hard to control
• Small operating region

Resolving Methods:

• Spark ignition
• Intake supercharging
• EGR

Fig. 1 Constraints on the range of HCCI operating conditions
OKP (Optimized Kinetic Process)

OKP:
- Heat exchange from exhaust and coolant
- Compression ratio at 13:1, with IVC for full-load SI operation

Principle of OKP

<table>
<thead>
<tr>
<th>MEASURES</th>
<th>CAI</th>
<th>CSI</th>
<th>VCR</th>
<th>OKP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compress ratio</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Pumping loss</td>
<td>A-</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Gas specific heat ratio</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Heat transfer loss</td>
<td>A</td>
<td>A</td>
<td>A-</td>
<td>A</td>
</tr>
<tr>
<td>High temperature decomposition</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Combustion time loss</td>
<td>A-</td>
<td>A-</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Friction loss</td>
<td>A</td>
<td>A</td>
<td>B+</td>
<td>A</td>
</tr>
</tbody>
</table>

Fig. 5 NSFC of the OKP engine in HCCI mode at 1500 rpm and different loads, compared with other engines.
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Original SI engine

Engine Characters

<table>
<thead>
<tr>
<th>Character</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder^stroke</td>
<td>4^4</td>
</tr>
<tr>
<td>Injection way</td>
<td>PFI</td>
</tr>
<tr>
<td>Coolant</td>
<td>Water</td>
</tr>
<tr>
<td>D×S (mm)</td>
<td>75×84.8</td>
</tr>
<tr>
<td>Spark order</td>
<td>1-3-4-2</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>10.5</td>
</tr>
<tr>
<td>Rated Power (kW^r/min)</td>
<td>78.0^6000</td>
</tr>
<tr>
<td>Rated T_tq (Nm^r/min)</td>
<td>135^4500</td>
</tr>
<tr>
<td>Emission standard</td>
<td>EU IV</td>
</tr>
</tbody>
</table>
Main parts of the engine test-bed

- Exhaust heat exchanger
- Higher CR piston
- Engine test-bed
- Control system
  - Camshaft with longer inlet duration
Intake air heat exchanging system

Exhaust heat exchanger

Coolant heat exchanger

External EGR
Transition from SI to HCCI

- At first, valve A, valve F and valve G (throttle valve) are opened, others are closed. The engine is started in SI mode.

- When the temperature of coolant and lubricant rise to 80°C, open valve B, C, and E. Then close valve A and F. The temperature of air will be increased by coolant heat exchanger and exhaust heat exchanger.

- The air-fuel ratio is corresponding to the air temperature. With the air temperature increasing, the air-fuel ratio becomes bigger and bigger. This correspondence is input in computer beforehand. The opening of valve G, is determined by air-fuel ratio.

- Once the air temperature reaches to 190°C, the valve G is opened entirely. The engine operating mode is transited from SI to HCCI.
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Fuel consumption SI VS HCCI

1600 r·min⁻¹ Operating Points

fuel consumption of HCCI, operating at 1600rpm, compared with SI
NOx emission SI VS HCCI

NOx emission of HCCI, operating at 2000rpm, compared with SI
Fuel consumption and NOx emission

contour of fuel consumption of HCCI and SI

contour of NOx emission of HCCI and SI
effect of spark ignition to SI→HCCI
Effect of spark ignition

- the spark advance is 10°CA BTDC, the effect of spark is insignificant. For the heat loss, the ignition phase of the first and the forth cylinders are delayed.
- the spark advance is 40°CA BTDC, the combustion status of these 4 cylinders are similar.

Difference between spark advance 40°BTDC and spark advance 10°BTDC
Effect of spark ignition

- The air-fuel mixture gas, near the spark, is ignited first.
- Then the temperature in cylinder is increased. When the temperature reach to high enough, other gas begin to auto-ignite.
The effect of supercharging:

- With intake pressure rising,
  - peak cylinder pressure
  - Pressure rise rate
  are increased,
  - and the phase of
  - Peak cylinder pressure
  - Heat release rate
  are advanced.

The rising intake pressure also leads to higher Pressure rise rate. So the combustion must be delayed. EGR is a good measure.
Potential of supercharging and EGR

Gradient = \frac{d \ (\text{BMEP})}{d \ (p_{\text{intake}})} = 5.9\text{bar/}(100\text{kPa})

n=1400\text{r/min}

\begin{itemize}
  \item BMEP of SI engine: 11\text{bar}
  \item P_{\text{in}}=2000\text{kPa}, \ BMEP=8\text{bar}
\end{itemize}
With supercharging and EGR, HCCI operating region is expanded. In HCCI mode, the torque is about 50% of SI mode.

With supercharging and EGR, the maximum of $T_{\text{eq}}$ is increasing at higher engine speed.

Operating region of HCCI with supercharging and EGR, compared with SI.

- $P_{\text{in max}} = 1.5\, \text{atm}$
- $EGR_{\text{max}} = 45\%$
- $BMEP_{\text{max}} = 6.5\, \text{bar}$
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Conclusions

- The fuel consumption of the engine operating in HCCI mode is 15% lower than in SI mode. Compared with SI mode, the NOx emission of HCCI mode is decreased by 90%.

- When temperature is not high enough, with Spark ignition, the combustion phase can be advanced and the cylinder-to-cylinder variation is decreased. And with spark ignition, the transition from SI to HCCI would be more easily achieved.

- With supercharging and EGR, the operating region of HCCI is expanded to about 50% of original SI engine.
Thanks for your attention!