Research Activities of LVK
Engine Laboratory
Personnel

Head: Prof. Dr.-Ing. G. Wachtmeister

Administration / organization:

Research and teaching:

2 secretaries
2 senior engineer
29 scientific engineers
2 plant engineers
test bed technician
electronic engineer
electronic technician
foreman
5 workshop-employees
2 apprentices
research students
Testbeds

dynamic asynchronous machine
DC-machine
monitoring-room
eddy current brake
water brake

gas supplied

tb. 1
250 kW 9500 rpm
tb. 2
2 a
70 kW 8000 rpm
2 b
220 kW 10000 rpm

1 a
420 kW 4000 rpm
1 b
44 kW 6500 rpm

3 a
380 kW 9000 rpm
3 b
150 kW 10000 rpm

4 a
80 kW 7500 rpm
4 b
80 kW 7500 rpm

5 a
44 kW 6500 rpm
5 b
44 kW 6500 rpm

700 kW 5500 rpm
250 kW 9500 rpm + 380 kW 6000 rpm as Tandem

80 kW 7500 rpm
Agenda

• Overview of Project Activities

• Influence of H2 admission in lean burn gas engines

• Unburned Hydrocarbons of Gas Engines

• Oil Flow and Distribution at Piston/Piston Rings
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# Field of Activities 1/4

## Combustion process development

- Diesel
- Otto
- Gas

### Experimental

- Injection
- Spray Chamber
- Thermodynamic engines
- Engines with optical access

### Simulation

- 0D / 1D Simulation
- CFD-Simulation
- Combined CFD-FEM Calculation

### Tools development

- Phenomenological combustion models
Field of Activities 2/4

Tribology of Piston / Piston Rings / Liner

Friction Measurements
Floating Liner

Experiment

- Movements of Rings and Piston
  - Axial
  - Radial
  - Circumferential
- Pressure distribution within ring package
- Oil film thickness
- Oil condition

Oil Flow/Distribution at Piston and Liner

Simulation

CFD-calculation
- Blow By resp. Reverse Blow By
- Oil flow from combustion chamber to crankcase
Field of Activities 3/4

Gas Engines

• Mini Combined and Power Unit
• Lean burn Passenger Car Engine
• Combustion Process Development
  • Spark ignition
  • Prechamber
  • Pilot fuel
• Unburned Hydrocarbons
• BMEP 30bar
• Formaldehyde Emission
• Dual Fuel Combustion
Field of Activities 4/4

Alternative Fuels

• Hydrogen
• Biogas
• Vegetable oil
• Oxygenated Fuels
Partners

- FVV: Forschungsvereinigung Verbrennungskraftmaschinen (FVV-Eigenmittel, Aif), German association of combustion engines manufacturer and supplier
- BFS: Bayerische Forschungsstiftung (Bavarian research association)
- DFG: Deutsche Forschungsgesellschaft (German research foundation)
- Different research foundations (z.B. Projektträger Jülich, Fachagentur Nachwachsende Rohstoffe)
- Industrial research i.e.
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Singe Cylinder Gas Engine Industrial Size

<table>
<thead>
<tr>
<th>Characteristics of LVK – single cylinder gas engine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bore</strong></td>
</tr>
<tr>
<td><strong>Stroke</strong></td>
</tr>
<tr>
<td><strong>Displacement</strong></td>
</tr>
<tr>
<td><strong>Epsilon (adjustable)</strong></td>
</tr>
<tr>
<td><strong>Peak Pressure</strong></td>
</tr>
<tr>
<td><strong>Valve Train</strong></td>
</tr>
<tr>
<td><strong>Variable Valve Timing</strong></td>
</tr>
</tbody>
</table>
Test Boundary Condition

- Natural gas composition (Munich city gas)

<table>
<thead>
<tr>
<th>Species</th>
<th>mol.%</th>
<th>Species</th>
<th>mol.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>94.87</td>
<td>CO₂</td>
<td>0.79</td>
</tr>
<tr>
<td>C₂H₄</td>
<td>3.31</td>
<td>N₂</td>
<td>0.53</td>
</tr>
<tr>
<td>C₃H₈</td>
<td>0.34</td>
<td>Others</td>
<td>0.16</td>
</tr>
</tbody>
</table>

- H₂ volume: 0, 10, 20, 30 vol.%

Operating conditions

- Air mass flow constant
- IMEP: 18 - 20 bar
- Turbocharger efficiency: 75%
Combustion Stability

Standard deviation of pmi [%]
[LP1, etaTC 75%, MaxF, MFB50 = 13° after TDCF]
THC-Emission

THC Emissions
[LP1, etaTC 75%, MaxF, MFB50 = 13° after TDCF]

- NG
- HNG10
- HNG20
- HNG30

Due to lower hydrocarbons in the fuel

Due to improved combustion
NOx-Emission

NOx Emissions
[LP1, etaTC 75%, MaxF, MFB50 = 13° after TDCF]
Indicated Efficiency

Indicated efficiency

[LP1, etaTC 75%, MaxF, MFB50 = 13° after TDCF]
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Influence of Equivalence Ratio and Combustion Phasing

Efficiency-THC trade-off at MFB50%-variation
Insufficient compensation of burning efficiency losses (later MFB50%) by higher fuel conversion rate
Ignition System

⇒ Extended operating range (lean and knock limit) with prechamber
⇒ Lower NOx levels reachable
⇒ Earlier COC at constant NOx attainable

Spark-Plug

Prechamber (unscavenged)
Ignition System

Spark-Plug

Prechamber (unscavanged)

Operation with prechamber:

⇒ Same level of efficiency at lower THC (lines)
⇒ Vice versa: same level of THC at higher efficiency
⇒ Higher THC-Level at max. efficiency due to leaner mixture
Mixture Formation

- Venturi mixer with crankangle-synchronous gas injection
- Gas supply
- Perforated downpipe
- Modified receiver-pipe for PFI-Mode
- Gas-Air-Mixture
- PFI-Duct-Geometry
Mixture Formation

Mixture formation via homogenizer

Port-Fuel-Injection

Additional Info.: Operating range comparable; COC slightly later due to knock limit with PFI-Mode

Increased THC (and CO) due to local too lean and rich mixture with PFI-Mode

Homogeneous mixture should be intended
Optical Set-up

- Piston Bowl (cylindrical)
- Quartz glass insert
- Elongated composite piston
- Line of sight w. high speed cam.
- Dry running piston rings and bearing strip
- 95 mm
Optical Investigations of the First Flame Propagation

*Dark red means that the flame is present in 100% of the cycles at the shown crank angle*
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Project Overview

► Design of measurement techniques for tribological studies in the piston ring area

- Design of a single cylinder petrol engine and measurement technologies
- Test and validation of measurement technologies for:
  - Lubricating Oil film thickness,
  - Oil transport and distribution,
  - Piston secondary and piston ring movement,
  - Piston ring joint position,
  - Ring land pressure,
  - Component temperatures,
  - Blow-By

2013

2014

2015

Start Kolbenring-Öltransport 1…

Fired Engine Operation

Test and validation of measurement technologies

Start Kolbenring-Öltransport 2…
Research Engine

<table>
<thead>
<tr>
<th>Engine data</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore x stroke</td>
<td>82.5 mm x 92.8 mm</td>
</tr>
<tr>
<td>Standard components</td>
<td>Piston, conrod</td>
</tr>
<tr>
<td>Timing drive</td>
<td>2 inlet valves, 2 exhaust valves</td>
</tr>
<tr>
<td>Maximum peak pressure</td>
<td>110 bar</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>9.5 : 1</td>
</tr>
<tr>
<td>Maximum engine speed</td>
<td>6500 rpm (with measurement link 4000 rpm)</td>
</tr>
<tr>
<td>Flywheel mass</td>
<td>1.5 kgm²</td>
</tr>
<tr>
<td>Mass balancing</td>
<td>1. and 2. engine order</td>
</tr>
</tbody>
</table>
Data Transfer via Grashopper Link

<table>
<thead>
<tr>
<th></th>
<th>Δα (Joint 1)</th>
<th>Δβ (Joint 2)</th>
<th>Δγ (Joint 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDC - BDC</td>
<td>26.7°</td>
<td>5.6°</td>
<td>32.2°</td>
</tr>
</tbody>
</table>

Crankcase
Optical fiber connector
Wire connector
Thermocouples, Capillary tubes

Measurement link case
Optical Access with Fiber Wires

- Piston
- Optical fibers
- Wires
- Tube
- Pin
- Conrod
- Coupling arm
- Needle bearing
- Link
- Pedestal
- Bearing box
- Tube support Piston
- Screw
- Shaft nut
- Wires
- Optical fibers
- Needle bearing bush
- PTFE-Bearing shell
- Length compensation
- 0° [CA] (TDC)
- Bearing box Tube
- PTFE ball
2000 [rpm]

Cold clearance: 0.09 mm (top) - 0.06 (bottom)
Circumferential Piston Ring Motion

Measured with Co$^{60}$ sample with 69 kBq in piston ring 2
Circumferential Piston Ring Motion

- Engine Speed [rpm]
- IMEP [bar]
- Counts [1/s]
- Angle of Sample to ATS [°]

Graphs showing engine speed, IMEP, counts, and angle of sample to ATS over time.
Oil Film Thickness with LiF

a. Laser (1.5 W)
b. 50/50 Beam splitter (15)
c. Mirror (32)
d. Dichroic Mirror (16)
e. Fiber Coupling (16)
f. Filter & Convex Lens (16)
g. Photodiode (16)
Measured Oil Film Thickness

- Piston skirt chamfer
- Cylinder liner
- Optical fibers
- Ferrule with optical fiber

Graph showing oil film thickness at different crank angles (CA) and strokes with various IMEP levels.
We have already achieved a high level insight into the individual mechanisms of a combustion engine.

We have pushed the combustion engine to a high mature level.

But we still have a lot to do!
Many thanks for your kind attention

Particular thanks to ClassNK for the very fruitful cooperation