Efficiency Increase of a High Performance Gas Engine for Distributed Power Generation

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Agenda

• Introduction
• GE’s Jenbacher Type 6 gas engine
• Gas exchange
• Combustion
• Summary
Introduction

GE’s Jenbacher gas engines for distributed power generation...

...provide electrical and thermal energy in a flexible, efficient & reliable manner – onsite and with short lead time

...operate with various types of fuel gas and low pollutant emissions

...serve 50 and 60 Hz grids, operate in grid-parallel and island mode

...cover an electrical power range from 250 to 9 500 kW

...offer electrical efficiencies up to 49.0 % and CHP efficiencies >90 %

...take the lead in special gas applications
Introduction

Future Requirements

Customer

• Investment costs
• Operation costs
• Availability
• Operation flexibility (gas comp. & ambient conditions)
• Lead time from stopped engine to full power to the grid
• Compliance to grid-code requirements (voltage drop)
• Compliance to emission limits

Thermodynamic development

⇒ Specific power output
⇒ High electrical efficiency...
⇒ Distance to knock and misfire borders
⇒ Methane number requirement
⇒ Power de-rating due to ambient conditions
⇒ Transient behavior
⇒ ...especially at low NO\textsubscript{X} emissions
# Introduction

**GE’s Jenbacher Type 6 gas engine**

<table>
<thead>
<tr>
<th>Engine version</th>
<th>J624 H</th>
<th>J620, 616 and 612 F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine process</td>
<td>4-stroke spark ignition engine with lean A/F mixture</td>
<td></td>
</tr>
<tr>
<td>Mixture preparation</td>
<td>Gas-mixer upstream of turbocharger</td>
<td></td>
</tr>
<tr>
<td>Turbocharging</td>
<td>2-stage (2-stage mixture coolers)</td>
<td>1-stage (2-stage mixture cooler)</td>
</tr>
<tr>
<td>Gas exchange</td>
<td>Single cylinder heads with 4 valves per cylinder</td>
<td></td>
</tr>
<tr>
<td>Advanced early miller timing</td>
<td></td>
<td>Moderate early miller timing</td>
</tr>
<tr>
<td>Combustion concept</td>
<td>Scavenged prechamber with passive prechamber gas valve</td>
<td></td>
</tr>
<tr>
<td>Ignition</td>
<td>MORIS high energy ignition system, spark plug</td>
<td></td>
</tr>
<tr>
<td>Power control</td>
<td>CBP and throttle valve</td>
<td></td>
</tr>
</tbody>
</table>
Introduction

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</thead>
<tbody>
<tr>
<td>Bore / Stroke [mm]</td>
<td>190 / 220</td>
<td></td>
</tr>
<tr>
<td>Displacement [dm³]</td>
<td>6.24 per cylinder</td>
<td></td>
</tr>
<tr>
<td>BMEP [bar]</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>Rated speed [1/min]</td>
<td>1500 (50 Hz), 1500 with gearbox (60 Hz)</td>
<td></td>
</tr>
<tr>
<td>Engine power [kW_{el}]</td>
<td>4400</td>
<td>3350, 2680 and 2010</td>
</tr>
<tr>
<td>Electrical efficiency [%]</td>
<td>46.3 @ MN &gt;83</td>
<td>45.6 @ MN &gt;84</td>
</tr>
<tr>
<td>Total efficiency [%]</td>
<td>90.3</td>
<td>89.1</td>
</tr>
</tbody>
</table>
Introduction

GE’s Jenbacher Type 6 gas engine

• More than 25 years of proven service
• More than 3,500 engines across the globe
• Average availability of 98%
Gas Exchange.
Efficiency Potentials
Gas Exchange

Cylinder head

- New version for future BMEP increase
- Opportunity used to improve flow characteristics of IN and EX ports
- Smart cooling gallery to reduce IN port surface temperatures
- Increased volumetric efficiency and reduced gas exchange losses

⇒ + 0.15 % points in engine efficiency
Gas Exchange

Cam shaft

- Potential for higher valve accelerations on the intake side
- Layout of IN valve lift, Miller timing / CR, valve overlap & EX valve opening

⇒ + 0.15...0.5 % pts in engine efficiency
⇒ + 5 K in intake manifold mixture temp.

J624 H
- advanced Miller timing
- very high potential boost pressure

J6xx F
- moderate Miller timing
- limited boost pressure
Gas Exchange

Variable valve train

- Engine efficiency during **steady state** operation can be increased by using a continuously variable intake valve closing for power control
- **Transient** response during load acceptance can be improved as well

**Efficiency benefit**
- closing CBV, advancing Miller timing
  ⇒ higher boost pressure, improved gas exchange

**Transient benefit**
- Reducing Miller timing at part load (no knocking)
  ⇒ optimal cylinder filling, fast power pick-up
Combustion.

Efficiency Potentials
Combustion

The low NOₓ challenge

- Lower NOₓ settings ⇒ leaner mixture in main chamber
  ⇒ higher losses in combustion (…misfiring)
  ⇒ higher losses in gas exchange

- Future emission trends ⇒ combined optimization of main combustion chamber and prechamber
Combustion

Main combustion chamber

- Various shapes have been investigated by CFD simulation and SCE testing
- Compact main combustion chamber increases average flow turbulence ⇒ increased combustion speed and stability, reduced knocking

![Graphs depicting Mean Turbulent Kinetic Energy and Burn Rate for different piston shapes: Flat-shaped piston, Bowl-shaped piston A, and Bowl-shaped piston B. The graphs show CFD simulation and SCE measurement results.](image)
Combustion

Main combustion chamber

- Piston bowl reduces local TKE $\Rightarrow$ incomplete combustion and knocking
- Trade-off: Global TKE level $\Leftrightarrow$ flame propagation at cylinder periphery

### Graphs

- **“global”**
  - Mean TKE Level
  - Loss in Real Comb.
  - Piston Shape Variant: Flat, Bowl A, Bowl B

- **“cylinder periphery”**
  - TKE Level inPeriph.
  - HC Losses
  - Piston Shape Variant: Flat, Bowl A, Bowl B

**SCE measurement**

**CFD simulation**
Combustion

Prechamber

- Sophisticated combination of A/F ratio and volume
  ⇒ best possible combination of flame torch impulse and NO$_x$ formation
- Prechamber design and operation parameters have been optimized

- Main challenge is to reduce prechamber NO$_x$ w/o reducing flame torch impulse
Combustion

Prechamber gas system

• Flame torch impulse depends strongly on prechamber A/F ratio
  ⇒ appropriate A/F ratio setting required for stable combustion @ low NO\textsubscript{X}
• Detailed tuning of prechamber gas system results in very similar prechamber gas amounts for all cylinders

Balanced system

• 70 % reduction in min-max spread

Positiv impact on

• Combustion stability
• Emission level
• Thermal/mechanical stress
Combustion

Final results of combustion development

• MCE results @ 24 bar BMEP, 250 mg/Nm³ NOₓ, equal PFP and equal CR
• Combustion duration considerably shorter ⇒ higher engine efficiency
• COV_{IMEP} about 30 % lower ⇒ robust engine operation at very low NOₓ
Combustion

**Final results of combustion development**

- Lower losses in real combustion and wall heat
- High A/F ratio and short combustion duration
  \[ \Rightarrow \text{reduced knocking tendency} \]
  \[ \Rightarrow \text{higher CR} \Rightarrow \text{higher ideal engine efficiency} \]

\[ +0.3\%\text{ pts} @ 500 \text{ mg/Nm}^3 \text{ NO}_x \]
\[ +0.6\%\text{ pts} @ 250 \text{ mg/Nm}^3 \text{ NO}_x \]
Summary

Potentials for further thermodynamic development

• The GE Jenbacher Type 6 gas engine family offers a very high electrical efficiency of up to 46.3% at 24 bar BMEP already today

• Gas exchange and combustion can be improved, especially at low NO\textsubscript{X}
  ⇒ electrical efficiency, thermal efficiency, robust operation at low NO\textsubscript{X}, power de-rating due to ambient conditions and pollutant emissions

• Technical conditions for a future BMEP increase and for an improved transient performance are being created

• Apart from WG and VVT the stated measures will not increase engine costs

There are still considerable potentials for further thermodynamic improvements – also for a high performance gas engine like the J624 H
Thank you for your attention!
Questions?
Type 6 Gas Engine

Core applications

- Coal mine gas: >150 delivered
- Landfill gas: >70 delivered
- Sewage gas: >50 delivered
- CHP applications: >2,500 delivered
- Flare gas: >70 delivered
- Special gas: >50 delivered
- Biogas: >40 delivered
- Greenhouse application: >700 delivered
Introduction

Development Methodology
Type 6 Gas Engine

Be global... act local

- More than 3,500 GE’s Type 6 Jenbacher engines delivered
- Generating a total of ~9 GW of power
- Powering an equivalent of over 15 Million EU homes
Type 6 Gas Engine

Variants

**Jenbacher Type 612**
- 12 cylinder
- El. output: 2 MW (22bar)
- El. efficiency 45.0%
- Fleet > 530 engines delivered

**Jenbacher Type 616**
- 16 cylinder
- El. output: 2.7 MW (22bar)
- El. Efficiency 45.5%
- > 1,000 engines delivered

**Jenbacher Type 620**
- 20 cylinder
- El. output: 3.3 MW (22bar)
- El. efficiency 45.6%
- > 1,800 engines delivered

**Jenbacher Type 624^2**
- 24 cylinder
- El. output: 4.4 MW (24bar)
- El. efficiency 46.3%
- Two stage charging
- >150 engines delivered