Simulation-based study on turbocharging dual-fuel engines
Paper no. 187

C. Christen, D. Brand, CIMAC 2013
Dual-fuel engines
As a solution for IMO Tier III

**GAS MODE**
- Low NO\textsubscript{x} emission
- NO\textsubscript{x} Level < IMO Tier 3

**GAS or DIESEL MODE**
- Regular NO\textsubscript{x} emission
- NO\textsubscript{x} Level < IMO Tier 2
Dual-fuel engines
Established engine technology

- Moderate power density
- Single stage turbocharging
- Low compression ratio
- Constant speed or CPP operation
- Micro pilot spray ignition
Dual-fuel engines
Development targets: Fuel efficiency and power density

**FUEL EFFICIENCY**

- Improved closed cycle efficiency
  → Increased $p_{\text{max}} / \text{imep}$
  → Increased CR $\varepsilon$
  → Miller cycle

- Reduced gas exchange losses
  → Improved turbocharger efficiency
  → Fuel-efficient control device

**POWER DENSITY**

- Extending knock limit to allow for higher bmep
  → Miller cycle
  → Lean burn combustion
Dual-fuel engine process design challenges
Pilot spray ignition vs. knocking combustion
Dual-fuel engine process design challenges
Pilot spray ignition vs. knocking combustion

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>KNOCK</th>
<th>IGNITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMEP</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>CR ε</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>MILLER</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>IGNITION TIMING</td>
<td>+</td>
<td>+</td>
</tr>
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Optimal combination
→ high bmep
→ high efficiency

Boundary conditions / limitations

<table>
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<tr>
<th>Parameter</th>
<th>Limitation</th>
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<tbody>
<tr>
<td>Max. cylinder pressure $p_{\text{max}}$</td>
<td>Below limit $p_{\text{max}} = 220$ bar</td>
</tr>
<tr>
<td>Turbine inlet temperature $T_{\text{TI}}$</td>
<td>Below limit $T_{\text{TI}} = 530$ °C (HFO mode)</td>
</tr>
<tr>
<td>Pilot spray ignition delay</td>
<td>Below threshold value</td>
</tr>
<tr>
<td>Knock integral</td>
<td>Below calibrated value</td>
</tr>
<tr>
<td>Air fuel ratio $\lambda_V$</td>
<td>Constant (gas), above limit (diesel)</td>
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</table>
Cycle optimization simulation results
Combined result of diesel and gas engine operation

![Graph showing engine efficiency and compression ratio](image)

- Engine Efficiency $+\Delta \eta_{\text{Mot}}$ [%]
- Compression ratio $\varepsilon$ [-]

1% point

Established dual-fuel technology

Case study bmep = 26 bar

bmep [bar]
- 20
- 22
- 24
- 26
- 28

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Cycle optimization simulation results
High compression ratio calls for strong Miller effect

Established dual-fuel technology

Case study

Charge air pressure

Compression ratio $\varepsilon$ [-]

Single-stage
Two-stage

bmeP [bar]
- 20
- 22
- 24
- 26
- 28

Optima
Engine cycle optimization in gas mode
Improving gas exchange

Cylinder pressure

VVT control

Throttle control

EWG control

Increased turbocharging efficiency

\( V / V_D [-] \)
Air management
ABB’s contribution for optimized engine process

**Power2**
High charge air pressure for strong Miller timing
High turbocharging efficiency for improved fuel efficiency

**VCM**
Fuel efficient air/fuel ratio control device
Flexible Miller timing
Case study
Simulation setup and boundary conditions

<table>
<thead>
<tr>
<th>Simulation Case</th>
<th>Bmp</th>
<th>CR</th>
<th>Turbocharging system</th>
<th>Bore</th>
<th>( \lambda_V ) control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>20 bar</td>
<td>Ref.</td>
<td>single-stage</td>
<td>Ref.</td>
<td>EWG</td>
</tr>
<tr>
<td>VCM</td>
<td>26 bar</td>
<td>+4</td>
<td>two-stage</td>
<td>-6%</td>
<td>VCM</td>
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Rated engine power ≈ 5 MW

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Case study results **CONSTANT SPEED**

\( \Delta \text{bsfc} \) against reference

Reduction of brake-specific fuel consumption

14 to 20 g/kWh

Increased potential in gas mode at engine part load with **skip firing enabled by VCM**

**GAS MODE**          **DIESEL MODE**

**bsfc [g/kWh]**

```
Engine load [-]
0.2 0.4 0.6 0.8 1.0 1.2
```

**Reference**

```
skip firing
```

```
10 g/kWh
```

Case study results **FPP**

Δbsfc against reference

Reduction of brake-specific fuel consumption in **FPP** mode

15 to 20 g/kWh
Conclusions
Paper no. 187

Potential for dual-fuel engines according to simulation

- **Power2** and **VCM** as a package allow for a step-change in fuel efficiency and power density
- **VCM** enables FPP operation on dual-fuel engines
Thank You for Your Attention
Power and productivity for a better world™
Engine cycle optimization
Air path loss reduction

Increased Miller Effect

Open Throttle

Increased turbocharging efficiency

\[ \Delta p_{\text{Engine}} \]

\[ \Delta p_{\text{Engine,VCM}} \]

\[ p_{\text{TI}} \]
Engine cycle optimization
Two-stage turbocharging efficiency improvement

Increase of TC system efficiency due to intercooling

\[ \frac{\eta_{2st}}{\eta_{1st}} \]

**Case study**

\[
\begin{align*}
T_{Amb} & = 25 \, ^\circ C \\
T_{IC} & = 60 \, ^\circ C 
\end{align*}
\]

Example

**Single-stage:**
\( \eta_{s,C} = 82\% \)

**Two-stage:**
\( \pi_{tot} = 6-8 \)
\( \eta_{s,C,eq} \geq 90\% \)
ABB’s Valve Control Management **VCM**

Prototype Testing

- VCM has been tested on a medium speed engine
- Functionality and mechanical integrity have been proved
- Endurance tests have been carried out
  - > 1000 running hours on mechanical test rig
  - > 300 running hours on fired engine
- The prototype demonstrated maturity for industrial application
ABB’s Valve Control Management VCM
Working Principle

Full valve lift mode
- Control valve stays closed
- Synchronous movement of valves and camshaft
Early valve closure mode

- Control device opens during valve lift period
- Valve closes irrespective of camshaft position and the pressure accumulator is charged
- As the camshaft is reduced, the pressure accumulator passes its spring energy onto the camshaft
Power Control of Premix Gas Engines
Valve Control Management **VCM**

- a) Full lift
- b) Early valve closure
- c) Late valve opening with reduced lift
- d) Double valve lift
- e) Zero lift