Gas Mobile Marine

S4000M05-N
Gas Mobile Marine

Workshop on Modernisation of Danube Vessels Fleet

FN, April 2018, Peter Rank
Agenda

01 General Overview
02 Emission Legislation
03 Engine Concept
04 Technical Data / Features
05 Standard scope of supply
06 Shipside Gas System
07 Ratings, Portfolio & Market introduction
08 References
09 Customer Benefits
01 General Overview
General Overview
Main driving factors for Gas engines

<table>
<thead>
<tr>
<th>Large Reserves</th>
<th>Emission Regulations (ECA**)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing LNG*-Infrastructure</td>
<td>Low Gas Price</td>
</tr>
</tbody>
</table>

* LNG: Liquified Natural Gas
** ECA: Emission Controlled Area
General Overview
In-house Gas Experience

Rolls-Royce

Rolls-Royce Power Systems AG

Mobile Applications
- High Speed Diesel Engines
- Propulsion systems

Stationary Applications
- High Speed Gas Engines
- Gas and Diesel Generator sets
- Power supply systems

Bergen Engines AS

Marine and Stationary Applications
- Medium Speed Gas Engines
- Medium Speed Gas and Diesel Generator sets

Rolls Royce Marine

Marine Design and Systems
- Ship design
- Shipside gas systems

Know how transfer
**General Overview**

**MTU Mobile Gas Portfolio Development**

**Marine**

**Marine application** has been chosen as lead application

- Existing experience in gas fuelled ships – also in house (Bergen)
- LNG infrastructure starts to develop from sea coast
- Technical rules and guidelines most developed (IGF-Code, DNV/GL, BV, LR)
- Highest technical requirements allows downgrade to land based applications
- Time to market
02 Emission Legislation
## Emission Legislation Overview

<table>
<thead>
<tr>
<th>Year</th>
<th>EPA</th>
<th>IMO</th>
<th>EU V</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td></td>
<td>IMO Tier III (NOx 2.0 g/kWh, PM not limited) only in emission controlled areas</td>
<td>EU V</td>
</tr>
<tr>
<td>2016</td>
<td>EPA Tier 4 (NOx 1.8 g/kW, PM: 0.04 g/kWh); 1000 -1400kW → 2017; 600-1000kW → Oct 2018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2019</td>
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<td></td>
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<tr>
<td>2020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

- **EPA**
  - > 2000kW since 2014

- **IMO**
  - IMO Tier III (NOx 2.0 g/kWh, PM not limited) only in emission controlled areas

- **EU V**
  - EU Stage V (NOx 1.8 g/kWh, PM: 0.015 g/kWh / PN: 1*10^{12} #/kWh)

IMO Tier III (in Emission controlled areas – ECA) EPA Tier 4
Emission Legislation Overview

Existing ECAs
Coast of Canada, USA & Hawaii, Puerto Rico, US Virgin Islands

Applied ECAs (January 1, 2021)
North Sea and Baltic Sea

**IMO Tier III**
Vessels constructed on/after 1st January 2016 need to be **IMO Tier III** certified, if operation area is an Emission Controlled Area
Exemption: Recreational purpose yachts <24m length WL and/or <500GT, Naval vessels

**EPA Tier 4**
Vessels registered in the US need to be **EPA Tier 4 certified**, if engines manufactured on/after 1st January 2016
Exemptions: recreational provision, testing,…

**EU V**
Engines (>300kW) for Inland waterway vessels used in EU need **EU V** certification from **1st January 2020** on
03 Engine Concept
S4000M05-N - Engine Concept
Engineering Target

- Diesel like performance
- Suitable for FPP applications
- Use of proven S4000 base engine
- Use of common S4000 parts
- Comply to latest emission regulation limits
  - IMO Tier III
  - EPA Tier 4*
  - EU V*
- Up to 2000 kW
- Heavy Duty Commercial Application
  - (1A rating)

* on request
S4000M05-N - Engine Concept

Technical Concept

Proven design of Core-Engine S4000M03 - Ironman

Lean burn gas engine Otto-principle

1-stage Bi-Turbo (MTU ZR)

Double-walled fuel piping for IGF code “gas safe machinery space”-concept

Footprint and Flywheel connection as S4000M03 - Ironman

Most engine options as S4000M03 – Ironman e.g.:
- exhaust outlet
- starting system
- PTO’s
04 Technical Data / Features
S4000M05-N – Technical Data

**Engine**

<table>
<thead>
<tr>
<th>Natural Gas Quality</th>
<th>MN &gt; 70</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power / Cylinder</strong></td>
<td>93 – 125 kW</td>
</tr>
<tr>
<td><strong>Engine speed</strong></td>
<td>600 – 1600 rpm</td>
</tr>
<tr>
<td></td>
<td>600 – 1800 rpm</td>
</tr>
<tr>
<td><strong>Gas consumption</strong></td>
<td>203 g/kWh @ 2000 kW @ 1800rpm</td>
</tr>
<tr>
<td><strong>Gas pressure before GRU</strong></td>
<td>5.5 - 8 bar</td>
</tr>
<tr>
<td><strong>Exhaust gas backpressure</strong></td>
<td>30mbar (design) / 85mbar (max)</td>
</tr>
<tr>
<td><strong>Mean time between overhaul</strong></td>
<td>30.000 hrs (standard 1A load profile)</td>
</tr>
<tr>
<td><strong>Cooling system</strong></td>
<td>HT/LT</td>
</tr>
<tr>
<td></td>
<td>Separate circuit charge air cooling</td>
</tr>
<tr>
<td><strong>Emission certification</strong></td>
<td></td>
</tr>
<tr>
<td>IMO Tier III</td>
<td></td>
</tr>
<tr>
<td>EPA Tier 4 – on request</td>
<td></td>
</tr>
<tr>
<td>EUV – on request</td>
<td></td>
</tr>
</tbody>
</table>

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S4000M05-N – Technical Features
Gas Specific Engine Components

- Ignition Controller
- Engine Control Unit
- Throttle Flap
- Waste Gate
- By-pass
- Cylinder Pressure Control
- Multi Point Gas Injection Valve
- Injection Lancet
- Spark Plug + Coil
S4000M05-N – Technical Features
Cylinder Pressure Based Combustion Control

Observation of the in-cylinder individual burn rate

in time analysis of:

- Start of combustion
- Combustion progress
- Knock
- Max. peakpressure
- Misfiring
- BMEP to determine engine power

Benefits:

- Minimization of the scatter band of the cylinder individual peak pressures.
- Control of max. firing pressure, eliminate knocking when MN went down (rich gas)
- Control of mean effective pressure, gain stability (lean gas)

![Graphs showing combustion pressure over crank angle with and without controlled combustion.](image)
**S4000M05-N – Technical Features**

**Interaction / function of key components**

- **Ignition**
  - Ignition controller
  - Control of ignition energy and timing based on spark plug wear

- **S4000M05-N – Technical Features**

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- **S4000M05-N – Technical Features**

  **Interaction / function of key components**

- **Ignition**
  - Ignition controller
  - Control of ignition energy and timing based on spark plug wear
Achievements:
- Performance map/range like Diesel
- Suitable for Commercial Marine applications
- Compatible to fixed pitch propeller and thruster

✓ Dyno test confirmed dynamic acceleration

→ First pure Gas high-speed engine with Diesel like performance in the market.
05 Standard scope of supply
16V4000M05-N - Scope of Supply
Standard Scope Overview

Gas Regulation Unit (GRU)

Local Operator Panel (LOP),
customer interface

16V4000M05-N pure-gas engine
06 Shipside Gas System (option)
Overview – Product Scope
Marine Heavy Duty Gas System

LNG – fuel system
(MTU-scope of supply)

- Tank (vacuum isolated) 10...50 (70) m³
- Bunkering station
- Cryogenic pump
- Vaporizer & Superheater
- Heat exchanger

MTU-basic scope (GRU plus engine)

- Gas regulating unit
- Double walled flexible gas hose
- Double walled gas pipe

Automation system tbd.
Shipside Gas System
Fuel gas system (LNG) - MTU’s system approach

<table>
<thead>
<tr>
<th>Shipside system</th>
<th>Standard MTU scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filling Station</td>
<td>MTU gas engine 16V4000M05-N</td>
</tr>
<tr>
<td>Storage tank with cold box</td>
<td></td>
</tr>
<tr>
<td>Gas Regulating Unit</td>
<td></td>
</tr>
</tbody>
</table>

Today we see high investment cost for LNG storage and processing system due to non standardized solutions which have to meet strong safety requirements.

- MTU has launched a R&D project to develop a standardized system solution
- Typical MTU applications like ferries or Tugs and workboats shall be in the focus
- MTU will team up with Rolls-Royce Marine to benefit from their large experience in LNG propulsion and storage systems.
Shipside Gas System
Fuel gas system (LNG) – overview

- Fuel storage hold space
- LNG-Tank
- Tank connection space, TCS
- Electronic control, monitor and safety system
- LOP local control, monitoring, interface system
- GRU LOP - control, monitoring and safety system
- GAS ENGINE
- GRU gas regulating unit

bunker station
Shipside Gas System
Fuel gas system (LNG) – implementation, for example
**BUNKER STATION:**

**task:**
connection point for the LNG supplier (ship/truck/…) to refill the tank and fulfill safety aspects.

**components:**
1. flange for coupling system (in dependence of LNG supplier)
2. break away coupling (safety)
3. filter
4. gas valve (pneumatic)
5. N2 interface (bottles or onboard system)
   - pressure, flow and temperature sensors
   - pneumatic/electrical panel (not shown)

!! picture shows a single bunkering station!!

**skid mounted bunker station:**
6. drip tray with capacity of appr. 200 liter
7. flange for removal of leaks, spilled fluids or other liquids
### Shipside Gas System

**Fuel gas system (LNG) – tank and TCS**

#### STORAGE TANK FOR LNG:

1. **Storage tank for LNG:**
   - Double walled tank (vacuum isolated / filled with perlite)
   - The volume depends on the ship and load profile.
   - Typical tank size for MTU gas engines: 10 … 100m³
   - Tank mounting position: horizontal or vertical

2. **TCS (tank connection space):**
   - Regasification of LNG to NG with temperature and pressure, needed for MTU engines (within limits).
   - Monitoring and control of the tank pressure
   - Monitoring of the tank level (filling / consumption)
   - Boil-off gas (BOG) handling
Shipside Gas System
Fuel gas system (LNG) – P&ID

- LNG tank
  - ~10, 25, 50, 100 m³ horizontal
  - 50 .. 65 m³ vertical

- cryogenic pump
- vaporizer
- super-heater
- buffer-tank (opt.)
Shipside Gas System
Fuel gas system (LNG) – Automation and control system

LNG Fuel system:

2 independent control and monitoring systems for:

- Control and monitoring system
- Safety system

visualization:

- engine control room
- control stand (bridge)
Shipside Gas System
Fuel gas system (LNG) – Automation and control system

Automation and control system:

The purpose of the control and safety system (LNG-fuel-system) is to perform control and monitoring of the LNG-fuel system and providing a safe operating environment for the vessel and crew.

Main process function:

- bunkering
- gas supply during normal operation (gas engines supply)
- Safety System (LNG-fuel-system) and monitoring to avoid critical situations
- Monitoring of all necessary information with regards to control of the regasification process in accordance to the acceleration behavior.
- Alarm processing
- Alarm monitoring
- Interface to the ship automation system
- Control and monitoring of the pneumatic panels

With customized graphics the Automation and control system displays information from the alarm-, control- and Safety System (LNG-fuel-system). This system will be delivered as a standalone system. A interface to the ship automation system shall be provided (standard bus system).

The primary function of the LNG control system is to maintain the required LNG-pressure conditions while supplying fuel gas at desired temperature and pressure to the gas engine. Connections to sensors located at critical points throughout the plant allows the control system the process.
Shipside Gas System
Engine monitoring – typical monitoring layout

Exemplary representation: ENGINE
Shipside Gas System
Fuel gas system (LNG) – typical monitoring layout

Exemplary representation: LNG-FUEL-System
Shipside Gas System
Fuel gas system (LNG) – safety system

- monitor safety critical elements for the LNG fuel system.

- will perform a series of predetermined actions to reduce the safety hazard and if the situation calls for it make sure the LNG Fuel system will be shut down and returned to a safe state.

- In the case of a safety critical event the Safety System (LNG-fuel-system) will execute appropriate action to reduce or eliminate safety risks.

- Is built up with several levels of control depending of the safety critical event.

- will monitor the level of dangerous gases at strategic places in the ship and along the LNG fuel system.

- Typical mounting places are double walled piping of gas supply to the engine and in the TCS. Gas detection are built on a system of dual sensing, where two gas sensors operate in pair.

- Is designed to monitor safety critical signals from the LNG fuel system as well other signals that are important to the safety of operating the LNG fuel system.
Shipside Gas System
Fuel gas system (LNG) – actual design studies

Brødrene Aa
a specialist for high speed catamarans (HSLC) made in carbon composite.

vertical tank solution
horizontal tank solution

cut through the boat hull
07 Ratings, Portfolio & Market introduction
## Planned Marine Portfolio

<table>
<thead>
<tr>
<th>Marine prop.</th>
<th>8V max 1000 kW</th>
<th>12V max 1500 kW</th>
<th>16V max 2000 kW</th>
<th>20V max 2500 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMO III / EPA 4* / EU V*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine gens.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMO III / EPA 4* / EU V*</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

- **16V4000M05-N for main propulsion** SOD Q04/2018
- **8V4000M05-N for main propulsion** SOD Q02/2020
- **12V4000 and 20V4000** development subject to market demand
- **Constant speed engine** development subject to market demand
- **EPA 4 (with oxi-cat) and EU V** 8V and 16V certification subject to market demand
### Portfolio, Ratings & Market introduction

#### Planned Main Propulsion Ratings and Availability

<table>
<thead>
<tr>
<th>Model</th>
<th>Power [kW]</th>
<th>Rated speed [rpm]</th>
<th>Availability (SOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8V 4000 M55RN</td>
<td>746</td>
<td>1600</td>
<td>Q02/2020</td>
</tr>
<tr>
<td>8V 4000 M65-N</td>
<td>1,000</td>
<td>1800</td>
<td>on request</td>
</tr>
<tr>
<td>16V 4000 M55RN</td>
<td>1,492</td>
<td>1600</td>
<td>Q01/2019</td>
</tr>
<tr>
<td>16V 4000 M55-N</td>
<td>1,840</td>
<td>1800</td>
<td>on request</td>
</tr>
<tr>
<td>16V 4000 M65-N</td>
<td>2,000</td>
<td>1800</td>
<td>12/2018</td>
</tr>
</tbody>
</table>

- **up to 1.000kW @1800rpm**
- **up to 2.000kW @1800rpm**

*SOD – 16V4000M65-N with Lloyds Register - ABS, BV, DNV/GL subsequently*
08 References
References

**High Speed Ferries:**
2x 2x 16V4000 gas engines @1.492kW
for Reederij Doeksen
Engine delivery in 2017

**Ro-Ro Ferry (field test engines):**
2x 8V4000 gas engines @ 746W
for Stadtwerke Konstanz
Engine delivery in 2020
09 Customer Benefits
Return On Invest
Comparison – Invest & Consumption Cost

Invest & Consumption* Cost over 15 years

<table>
<thead>
<tr>
<th></th>
<th>16V4000M65R</th>
<th>16V4000M65-N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exhaust regulation</strong></td>
<td>IMO III</td>
<td>IMO III</td>
</tr>
<tr>
<td><strong>Engine rating [kW]</strong></td>
<td>2.000</td>
<td>2.000</td>
</tr>
<tr>
<td><strong>Speed [1/min]</strong></td>
<td>1.600</td>
<td>1.800</td>
</tr>
<tr>
<td><strong>TBO [h]</strong></td>
<td>21,000</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>Load profile</strong></td>
<td>Standard (LF 53 / LI 8)</td>
<td></td>
</tr>
<tr>
<td><strong>Operating time</strong></td>
<td>60,000 h @ 15 years</td>
<td></td>
</tr>
<tr>
<td><strong>Urea cost</strong></td>
<td>0,35 €/l</td>
<td>-</td>
</tr>
<tr>
<td><strong>Oil cost</strong></td>
<td>4,50 €/l</td>
<td></td>
</tr>
<tr>
<td><strong>Coolant additive</strong></td>
<td>4,10 €/l</td>
<td></td>
</tr>
<tr>
<td><strong>Not included</strong></td>
<td>Maintenance cost</td>
<td></td>
</tr>
</tbody>
</table>

* Includes: Fuel, oil, coolant, urea (Green Ocean)
** Invest cost: Engine purchase + Tank system

Savings:
- Gas 0,9 € = ~ 0,1 Mio €
- Gas 0,6 € = ~ 5,2 Mio €
- Gas 0,4 € = ~ 8,8 Mio €

Current market price

Calculation March 2018
## S4000 Gas engine for Marine application Key Facts & Highlights

<table>
<thead>
<tr>
<th>Dynamic Acceleration Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>comparable performance characteristics to that of our series 4000 diesel engine for workboat application, no visible smoke, even at acceleration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Better environmental footprint compared with that of the diesel engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% less Carbon Dioxide (CO₂)</td>
</tr>
<tr>
<td>Health-threatening substances in the exhaust gas - such as nitrogen oxides, sulfur oxides, fine particulate matter - of gas-powered engines are reduced by 80 up to 100% compared to IMO II diesel engine</td>
</tr>
<tr>
<td>No Exhaust Gas After Treatment (SCR, Particulate Filter) required for IMO Tier III and EUV</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gas Safe Machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine built for “gas safe machinery space”</td>
</tr>
<tr>
<td>No need for separate engine housing and ventilation within the engine room</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>First high speed pure gas engine in high power range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Currently available gas engines are primarily medium speed engines</td>
</tr>
<tr>
<td>Pure gas high speed engines offer significantly less weight than medium-speed gas engines for the same performance → improved power-to-weight-ratio</td>
</tr>
</tbody>
</table>
## S4000 Gas engine for Marine application
### Key Facts & Highlights

<table>
<thead>
<tr>
<th>Multi Point Injection</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Cylinder individual injection of gas</td>
<td></td>
</tr>
<tr>
<td>- Identical combustion period in each cylinder</td>
<td></td>
</tr>
<tr>
<td>- Stable engine operation, increased availability</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engine Map</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- All propulsion modes possible (fixed and variable pitch propeller)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wide rpm range</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- The rpm range is suitable for fixed pitch propellers to provide low-cost drive systems</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cylinder Pressure Based Combustion Control</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Minimization of the scatter band of the cylinder individual peak pressures</td>
<td></td>
</tr>
<tr>
<td>- Control of mean effective pressure, gain stability</td>
<td></td>
</tr>
<tr>
<td>- Reduction of fuel consumption and emissions</td>
<td></td>
</tr>
</tbody>
</table>