Energy Efficient Gas Propulsion Systems with Hybrid Shaft Generator

Tobias Haack – Sales Manager
A comprehensive range of products....

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<th>Gas turbines</th>
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Rolls-Royce
Rolls-Royce Marine Engines Bergen

- New engine block, cylinder head and connecting rod machining centres (end 2008)
- Over 6300 engines sold worldwide, and more than 4000 engines still in operation
- 8 test cells + development test cell
- Docking facility for sea transportation
- RRM Foundry nearby

History:
- Established in 1943
- First diesel engine delivered 1946
- First HFO engine delivered in 1963
- First lean-burn gas engine delivered in 1991
- First marine gas engines for gas electric propulsion delivered 2006
- First 2nd generation marine gas engine delivered primo Dec. 2010
Rolls-Royce marine engines

Designed for robustness, harsh operational environments, and exceptional levels of reliability
Technology Drivers

• Emissions
  • \( \text{NO}_x \)
  • \( \text{SO}_x \)
  • Smoke / Particulates
  • \( \text{CO}_2 \)

• Fuel availability and price!!!
  • BP statistics: Reserve for gas is 63 years but only 46 years for oil
  • Prof. Dr.-Ing. Rulfs, TUHH:
    After 2030 HFO will not be the dominating cheap ship fuel anymore and will disappear around 2040
  • Except for short periods LNG was always cheaper than HFO:
    • HFO currently approx. 650$/t
    • MGO currently approx. 1000$/t
    • LNG currently approx. 500$/t (depending on shipping costs)
NOx Emission limits IMO

NOx emission for Bergen engines

- IMO Tier I (2000)
- IMO Tier II (2011)
- IMO Tier III (2016)

- B32:40 diesel with Clean Design notation
- C25:33 diesel with Clean Design notation
- B35:40 gas
- C25:33 gas

Rolls-Royce data - strictly private
Smoke issues…..

Visible smoke 1910

Visible smoke 2008

Invisible smoke 2007 – due to natural gas engine
EEDI: CO$_2$ Emissions

IMO has introduced the *Energy Efficiency Design* Index for newbuildings to decrease CO2 Emissions from the shipping sector:

Using the numbers of MEPC.1/Circ.681:

- 1 ton of Oil lead to **3.206 tons** of CO2 Emissions
- 1 ton of LNG lead to **2.75 tons** of CO2 Emissions
- The fuel oil consumption of a typical Diesel engine is **183 g/kWh**
- The fuel oil consumption of a Rolls-Royce gas engine is **150 g/kWh**

**CO2 Reduction of approx. 30%**
**Means a 30% lower attained EEDI**
But what about the Methan Slip?

• Methan has an approx. 20 times the Greenhouse effect of CO2.

• The Rolls-Royce lean burn gas engines have a Methan Slip of about 3 g/kWh (measured and confirmed by 3rd parties).

Taking MPEC conversion factors into consideration this still means approx. 20% less CO2.
Emissions - MDO versus Natural gas

SO2 med S = 0.1%

SO2 (0.1%)

NOx (g/kWh)

CO2 (g/kWh)

Particles
But what about the money?
Gas consumption comparison – Generators – constant speed: Single fuel vs Dual fuel

Specific Fuel Energy Consumption (kJ/kWh)

- Wärtsila 6L34DF
- Bergen C25:33L9AG

100 % load - 7.7 % diff.
50 % load - 16.1 % diff.

How many years of operation until the "risk premium" is covered?
Just a simple example…

6000 running hours @ 10 000 kW

<table>
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<tr>
<th>Fuel</th>
<th>g/kWh</th>
<th>$/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGO</td>
<td>183</td>
<td>950</td>
</tr>
<tr>
<td>Urea</td>
<td>9</td>
<td>800</td>
</tr>
<tr>
<td>LNG</td>
<td>150</td>
<td>550</td>
</tr>
</tbody>
</table>

Fuel costs of approx. 5 Million $ vs. 11 Million $
Dual fuel system meeting IMO Tier III:

- SCR reduce NOx
- Scrubber reduce SOx
- Filter reduce PM

More cost due to:
- Add Energy = CO2
- Add Urea
- Add maintenance
- Add Complexity

- Lube oil change over
- Fuel change over
- Water Separator
- Oil Separator
- Waste Material
Natural gas system meeting IMO Tier III:
Traditional Merchant Ship Propulsion

- Single engine
- Single mechanically driven propeller through a reduction gearbox
- Shaft generator used for production of electrical power at sea and powering tunnel thrusters during manoeuvring

**Pros**
- High efficiency
- Simplicity
- Reliability
- Low cost

**Cons**
- Shaft generator requires constant RPM
- Losses at propeller when operating at reduced speed
Variable Speed Operation

- Operation in combinator mode
  - Variable engine speed and propeller pitch
- Maintains efficiency of propulsion system during part load
  - Reduced rotational losses at propeller
  - Engine operates at better specific fuel consumption

![Propeller shaft Input power as a function of RPM](image)
Hybrid Shaft Generator

- Conditions power coming from the shaft generator
- Switchboard is supplied with constant voltage, constant frequency and matched phase angle
- Allows use of combinator mode during generation from shaft generator
- Enables recovery of power previously wasted through propeller rotational losses
- Significant efficiency gains
Hybrid Shaft Generator

- Combinator mode, normal steaming
Hybrid Shaft Generator

- Combinator mode with parallel generation
Hybrid Shaft Generator

- Diesel/gas electric mode, main engine can also be used for boost mode
Hybrid Shaft Generator

- Shore connection mode
Hybrid Shaft Generator Example 1

- Reduction in vessel speed
- Reduction in propeller RPM (arrow A)
- Vessel propulsion power requirement reduces (arrow B)
- HSG can still supply switchboard with electricity at correct frequency and voltage despite RPM change
Hybrid Shaft Generator Example 2

- Constant speed, reduced RPM
- HSG recovers up to 241kW, from rotational losses
Ships on Order

- **Sea-Cargo 132.8m gas fuelled cargo vessel**
  - Believed to be world’s first LNG main propulsion vessel with simple mechanical propulsion
  - 5,600 tonnes cargo capacity
  - 1,140 lane-metres RoRo capacity
  - Up to 94TEU of containers on deck

- **NSK Shipping 70m fish food carrier**
  - Approximately 2000 tonnes fish food pellets capacity
  - DP0 capability
  - Rolls-Royce gas engine, gas system, shaft generator, propeller, tunnel thrusters, controls and automation
The gas engines

- Types: C26:33L6-8-9
- Bore: 260 mm
- Stroke: 330 mm
- Power: max. 244 / 270 kW / cyl
- Speed: 600 – 1000 rpm
- Power range: 1460 – 2430 kWmech

References:

- Fjord1 Gas fuelled ferry (3xC26:33L9AG + 1xC25:33L9ACD)
- Island Offshore – UT776CDG PSV (2xC26:33L9AG + 2xC25:33L6ACD)
- Fjord1 Gas fuelled ferry (1xC25:33L9AG retrofit)
- NSK Shipping - Bulk carrier (1xC26:33L6PG)
The gas engines

- Types: B35:40L6-8-9 & B35:40V12, -16
- Bore: 350 mm
- Stroke: 400 mm
- Power: 420 / 440 kW / cyl
- Speed: 500 - 750 rpm
- Power range: 2520 - 8750 kWmech

References:

- Sea-Cargo, RoRo vessel (1xB35:40V12PG)
- Torghatten Nord, Gas ferry (2 x 1xB35:40V12PG / 2 x 1 x C26:33L9PG)
Lean Burn Gas engines

• More than 500 sold, over 400 gas engines in operation
• More than 20 mill running hrs experiences
• More than 140.000 running hrs
• Plants operating 8.500 hrs/year
• The five car ferries (16 engines) have logged more then 30000 running hours & more than 50000 port calls.
Summary

• Rolls-Royce lean burn Gas engines solve all emission regulations at once

• With the Rolls-Royce lean burn Gas engine the EEDI can be reached even with most current ship designs

• The Rolls-Royce lean burn Gas engine is superior in fuel oil consumption compared to Diesel- and DF engines.

• The small increase in investment costs pays off easily especially in combination with the Hybrid Shaft generator

• The Rolls-Royce lean burn Gas engine is a proven technology and LNG infrastructure is not a problem