The Dual Fuel..

An overview

- World's first LNG driven ocean going ship
  Owner: TOTE
  Ship type: Container ship
  Capacity: 3,100 TEu
  Dual Fuel engine type: 8L70ME-C8.2-GI

- World's first Methanol driven ocean going ship
  Owner: MOL
  Ship type: Methanol carrier
  Capacity: 50,000 dwt
  Dual fuel engine type: 7ES50ME-B9.3-LGIM

- World's first Ethane driven ocean going ship
  Owner: Hartmann Gas Carriers
  Ship type: LEG Carrier
  Capacity: 98,000 M³
  Dual Fuel engine type: 7G50ME-GIE

- World's first LPG driven ocean going ship (soon to be)
  Owner: Exmar
  Ship type: VLGC
  Capacity: 80,000 M³
  Dual Fuel engine type: 6G60ME-LGIP
The Dual Fuel...

An overview

World's first LNG driven ocean going ship
Owner: TOTE
Ship type: Container ship
Capacity: 3,100 TEU
Dual Fuel engine type: 8L25ME-C2-UGI

World's first Methanol driven ocean going ship
Owner: HCL
Ship type: Methanol carrier
Capacity: 50,000 cbm
Dual fuel engine type: 7S50ME-B9 3-LGIM

World's first Ethane driven ocean going ship
Owner: Harbours Gas Carriers
Ship type: LPG Carrier
Capacity: 30,000 m³
Dual Fuel engine type: 7S50ME-CIE

World's first LPG driven ocean going ship (soon to be)
Owner: EzGas
Ship type: VLGC
Capacity: 80,000 m³
Dual Fuel engine type: 6G36ME-LOGIN

\[ \frac{1}{2} \text{ Million} \]

MAN Energy Solutions
Future in the making

>65,000

LGIM

MAN Energy Solutions
Future in the making

>30,000

GIE

MAN Energy Solutions
Public

Peter C Quaade – Benaki Museum Event ©2019 23.10.2019
The Dual Fuel..

An overview

- >280 Confirmed sales
  112 in service (8 LGIM / 4 GIE)

- April 2019 > 500.000
  ME-GI design

- LGIP engines
  Prototype test December 2019

- Retro Fit solutions
  tankers, CV (ME to ME-GI, ME-GI to ME-GIE, ME to LGIP)

- ME-GIE a new member of the family, G60 ME-GIE
  Gas atomizers for Methane and Ethane
The Triple Fuel

- Diesel GI-6
- HFO GI-6
- Ethane GIE-29
- Methane GIE-29

- 100% load confirmed
- 4% fuel penalty at high load
- 1-3% fuel penalty at part load
- Minimum pilot up to max 85%, SDF above (Methane)
- 25/75 %

APPROVED
Dual Fuel Service Experience
Gas Injection Valves, Development history

Short nozzle design developed: GI-53
- Significant reduction of bulk temperatures
- Design confirmed on testbed Mar. 2016

Extra short nozzle design developed: GI-63
- Further reduction of bulk temperatures
- Improved stress distribution
- Design confirmed on testbed Aug. 2016

Alternative materials tested in service
- X90CrMoV18 G70ME-C-GI Dec 2017 Discontinued due to corrosion
- Böhler M390 G70ME-C-GI Dec 2017 Discontinued due to micro crack
- Tungsten G70ME-C-GI Jan 2019
- X90CrMoV18 L70ME-C-GI Jan 2018 Discontinued due to corrosion
- Böhler M390 L70ME-C-GI Jan 2018 Discontinued due to micro crack
- Tungsten L70ME-C-GI Oct 2018
ME-GI Service Experience

What is this?

Spindle tip of GIV
ME-GI Service Experience

Lifetime of gas injection valves (GIVs)

### ME-GI Engines
Guiding Overhaul Intervals and Expected Service Life

<table>
<thead>
<tr>
<th>Component</th>
<th>Overhaul interval (hours)</th>
<th>Expected service life (hours)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas injection valve (GIV)</td>
<td>4,000</td>
<td>16,000</td>
<td>Check and replace if required.</td>
</tr>
<tr>
<td>Valve nozzle</td>
<td></td>
<td>8,000</td>
<td></td>
</tr>
</tbody>
</table>

Spindle tip indicates very low wear after 10,000 hours:
Lapping marks are still visible

**Conclusion:**
GIV lifetime can be expanded to at least 32,000 hours
## ME-GI Service Experience

### ME-GI Engines
Guiding Overhaul Intervals and Expected Service Life

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<td>4,000</td>
<td>32,000</td>
<td>Check and replace if required.</td>
</tr>
<tr>
<td>Valve nozzle</td>
<td>4,000</td>
<td>&gt; 8,000</td>
<td></td>
</tr>
</tbody>
</table>

- **Cracked gas nozzle**
- **Extra short gas nozzle made in tool steel:**
  - **Lifetime 8,000 hours**

**Tungsten gas nozzle inspected after 3,000 hrs.**
**Lifetime >>8,000 hours**
ME-GI Service Experience, GIV atomizers

- Description on how to clean clogged atomizer has been produced
- GIV’s with clogged atomizers in service are returned for closer examination in Copenhagen at MAN - ES.
  Smaller bore engines and larger bore engines (45 and 70)
- New atomizer geometry will be tested in order to establish dependencies with atomizer temperatures
  Longer atomizers tested on G45, even longer will be tested.
- Seal Oil test launched this month
ME-GI Service Experience, GIV atomizers

Action Plan (continued)
- Investigate Seal Oil leakage, new GIV’s
- Exchange with used GIV’s
- Investigate Seal Oil leakage, used GIV’s
- G45 and G70 engine type
ME-GI Service Experience, GIV atomizers

- Test with different length of atomizers
ME-GI Service Experience, GIV atomizers

- Test with different length of atomizers
ME-GI Service Experience, GIV atomizers

- Test with different length of atomizers

1) At current load press Dual Fuel “Manual standby” on MOP
2) Take load up to 90% (or as high as possible)
3) Keep high load for about 20min
4) Press Dual Fuel “Start” to start DF mode
5) After change-over to DF mode, keep the high load for 5min
6) Reduce load to desired load staying in DF mode
7) Balance Pi, Pcomp, Pmax
ME-GI Service Experience, ELWI / ELGI valves

- ELWI / ELGI
  65 pcs investigated

Failing ELWI and ELGI valves

We have received a list from HHI with 63 failures of ELWI and ELGI. Approx. 1/3 of the claimed valves are ELWI and 2/3 of the valves are ELGI.

The valves can be arranged in four groups:

1) Valves with certain malfunction according to claim
2) Valves were seating ring has failed and in some cases blocked the valve
3) Claims were poor connection/cabling is a likely reason
4) Claims with no info about the failure

<table>
<thead>
<tr>
<th>Type of Failure</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>with certain</td>
<td>4</td>
</tr>
<tr>
<td>malfunction</td>
<td></td>
</tr>
<tr>
<td>according to</td>
<td></td>
</tr>
<tr>
<td>claim</td>
<td></td>
</tr>
<tr>
<td>Valves were</td>
<td>3</td>
</tr>
<tr>
<td>seating ring</td>
<td></td>
</tr>
<tr>
<td>has failed</td>
<td></td>
</tr>
<tr>
<td>and blocked</td>
<td></td>
</tr>
<tr>
<td>the valve</td>
<td></td>
</tr>
<tr>
<td>Claims were</td>
<td>26</td>
</tr>
<tr>
<td>poor connection</td>
<td></td>
</tr>
<tr>
<td>or cabling is</td>
<td></td>
</tr>
<tr>
<td>a likely reason</td>
<td></td>
</tr>
<tr>
<td>Claims with</td>
<td>20</td>
</tr>
<tr>
<td>no info about</td>
<td></td>
</tr>
<tr>
<td>the failure</td>
<td></td>
</tr>
<tr>
<td>mode</td>
<td></td>
</tr>
</tbody>
</table>
ME-GI Service Experience, ELWI / ELGI valves

Electrical Health Check

Portside junction box unit #3

1- Loose cables not fixed inside the junction box
2- Loose cables with ferule mounted, not insulated and fixed
3- Cable bracing with no back plate, have been installed and damaged the cable for Cylinder pressure #3

Many cables were found with damaged insulation, inside the junction boxes.
ME-GI Service Experience, Pilot Profile

- Fuel Injection Valves
- Solenoid Valves
ME-GI Service Experience, Pilot Profile

- Control Oil Pipe for GIV
Test of standard pilot injection profile and modified profile:
- Reliable pilot injection
- Pilot Oil consumption (SPOC)
HCU pressures – standard injection profile

Operation with present standard pilot injection profile:

- Pressure fluctuations before solenoid valve is significant.
- Pressure peak is above design limit of solenoid valve
ME-GI Service Experience, Pilot Profile

![Graph]

- SM Seahawk
- Mit_T36
- MOK_B20

![Image]

- Pressure transmitter
- FIVA valve
- Pressure transmitter Pos 565 (lubricator)
Operation with new pilot injection profile:

- Pressure fluctuations before solenoid valve are reduced significantly.
- Pressure peak is below design limit of solenoid valve.
- Pressure characteristic is now the same as for FO mode operation.
Status on implementing new pilot injection profile:

− New profile was implemented in service on a few vessel. Improvements have been confirmed by measurements.
− New profile already rolled out as standard on new engines.
− New profile will be installed on vessels in service, completed.
Pilot Profiles, SPOC
Low Load Gas operation

<table>
<thead>
<tr>
<th>D.S.</th>
<th>Diesel atomizer</th>
<th>Gas atomizer</th>
<th>Change to PI-93: For 1.5% pilot</th>
<th>Change to GI-70: For improved LL</th>
<th>New PIV: For 0.5% pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>GI-15</td>
<td>GI-66</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible, when released</td>
</tr>
<tr>
<td>9.5</td>
<td>EGR</td>
<td>GI-17</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible, when released</td>
</tr>
</tbody>
</table>
Test of reduced SPOC (1,5%) and Low Load Operation in service

- Re-building in Singapore after delivery from Korea:
  - Pilot atomizers, GI-15 to PI-93 incl. new spindle guide
  - Gas atomizers, GI-66 to GI-70
  - ECS parameter update (IMO Design checksum)
  - Amendment to IMO NOx technical file

- MAN ES Attendance:
  - Diesel re-commissioning and performance measurements
  - Gas re-commissioning, pilot oil profile / low load gas optimization
Test of reduced SPOC (1.5%) and Low Load Operation in service

- Diesel operation, Performance measurements
  - Re-commissioning of fuel index scaling and engine performance due to the increased injection duration of PI-93

R&D measurements Shop Test
Test of reduced SPOC (1,5%) and Low Load Operation in service

- **Gas operation, Performance measurements**
  - Re-commissioning of fuel index scaling and engine performance due to the increased injection duration of GI-70
  - Gas change over tuning/optimization
  - Pilot oil profile optimization and low load gas operation
Performance measurements

- **Diesel operation**
  - Comparison against sea-trial meas.
    - In general according to our expectations and in agreement with our previous RD measurements
    - Higher Pscav for PI-93 at high load due to slightly higher SFOC
    - Higher Air amount for PI-93 at high load due to slightly higher SFOC
    - Slightly lower exhaust temp. for PI-93

- **Gas operation**
  - Comparison against sea-trial meas.
    - In general according to our expectations
    - Similar Pscav/air amount for GI-70 at 85, 100% load. Similar tendency seen during R&D testing
    - Slightly lower exhaust temp. for GI-70
Performance measurements

- Gas operation, SPOC

- Pilot oil consumption
  - Measured during 1 hour with flowmeter after optimization
  - 45-50% reduction compared to sea-trial measurements at NCR/MCR
  - As expected and according to our previous R&D results
Performance measurements

- Gas operation, low load
  - Small endurance (15h) test showed successful low load gas operation is possible
  - Index ~20% (~6% load), Eng.Speed = 28 rpm (just below barred speed range)

- Low load GI operation
  - More stable GI operation with small flow atomizer
  - Full and stable GIV lift possible at low load
Pilot Injection Technology, PIV

Cut-off shaft lift

2.8 mm lift:

1.2 mm lift: reduced for pilot injection:

Only small atomizer holes open for pilot injection*

*Total nozzle flow area unchanged compared to standard FO nozzle

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Pilot Injection Technology, PIV

Pilot Injection Valve
Standard fuel valve with new pilot injection technology

225/300 bar HP oil is moving the thrust piece to reduce movement of cut-off shaft

Thrust piece lift 0 or 1.6 mm
Cut-off shaft lift 2.8 or 1.2 mm
Pilot Injection Technology

Application

1. Distribution block.
2. Arrangement of additional piping for PIV activation
Pilot Injection Technology

Control system

1. One on/off valve per cylinder.
2. Connection to hydraulic pressure supply.
3. Drain to baseplate or sludge
Thank you for your time...