Development of 4-Stroke Marine Dual fuel engine
(ClassNK joint R&D project)

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1. Motivation for DF engine development

- Stricter IMO emission limitation in ECA area (Tier III)
- Redundancy for fuel, depending on fuel price (oil or gas)

Shift from diesel to DF engine is increasing!
2.1 Project scheme (Project objective)

- NOx is less than...
  - Tier III limitation by gas mode operation (without aftertreatment e.g. SCR)
  - Tier II limitation by diesel mode operation
- Control strategy for switch over between diesel and gas mode
- Improvement of transient response behaviour on gas mode
- Secure the reliability
### 3.1 Project contents (Principal specification)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore x Stroke</td>
<td>[mm]</td>
<td>Φ280 x 390</td>
</tr>
<tr>
<td>Cylinder No.</td>
<td>[-]</td>
<td>6</td>
</tr>
<tr>
<td>Firing order</td>
<td>[-]</td>
<td>1-2-4-6-5-3</td>
</tr>
<tr>
<td>Engine speed</td>
<td>[min⁻¹]</td>
<td>720/750</td>
</tr>
<tr>
<td>Rated output</td>
<td>[kW]</td>
<td>1,730</td>
</tr>
<tr>
<td>BMEP</td>
<td>[MPa]</td>
<td>2.0</td>
</tr>
<tr>
<td>Peak firing pressure</td>
<td>[MPa]</td>
<td>17.7</td>
</tr>
<tr>
<td>NOx emission</td>
<td>[-]</td>
<td>≤TierⅢ (Gas mode)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤Tier Ⅱ (Diesel mode)</td>
</tr>
<tr>
<td>Main fuel</td>
<td>[-]</td>
<td>Natural gas (Gas mode)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MDO, MGO, HFO (Diesel mode)</td>
</tr>
<tr>
<td>Pilot fuel (Gas mode)</td>
<td>[-]</td>
<td>MDO or MGO (1% of total heat value)</td>
</tr>
</tbody>
</table>

This engine has **Reliability and durability**, because it is converted from DK-28 diesel engine which has many shipments and experiences.
3.2 Project contents (Engine structure)

Investigation for cylinderhead design

Layout investigation of pilot injector installation

FEM calculation was carried out.

Secure safety margin for material strength was confirmed by demonstration test.
3.2 Project contents (Engine structure)

Optimization for mixture formation

Configuration of gas admission was optimized by **CFD simulation**.

**Evaluation point**
- Capacity of gas admission valve
- Remain gas quantity in intake port
- Mixture homogeneity between gas and air in the cylinder
3.3 Project contents (Engine control)

Sophisticated Engine Control System (ECS) to realize comprehensive control functions

- Start & Stop sequence

- Speed/load control:
  - Diesel fuel injection pump rack control
  - Gas admission valve control

- Switch over procedure between diesel and gas mode

- Air fuel ratio control:
  - Waste gate
  - Compressor by-pass

- Ignition control by electronic micropilot injection (Common rail system)

- Gas supply management:
  - Gas pressure control
  - Sequencing of gas valves

- Safety, Monitoring and knocking control by in-cylinder pressure sensing
3.3 Project contents (Engine control)

Gas mode

Natural gas
(Test phase: Japan city gas 13A)

MDO or MGO
for Micropilot ignition

100%
MDO or MGO or HFO

Diesel mode

99%
MDO or MGO or HFO

1%
MDO or MGO
for injector nozzle cooling

Backup mode

100%
MDO or MGO or HFO
(Micro pilot trip)
3.3 Project contents (Engine control)

Knock control by retarding cyl.-individual injection timing

Data acquisition unit

Detection of knocking

ECS

Detection of Cylinder pressure

Cylinder pressure sensor

Injection

Retard of pilot SOI

Calculation of knocking by frequency analysis

Knocking!
3.4 Project contents (Safety consideration)

Inherently gas safe machinery spaces

Ventilation fan
30 times/hour
50% capacity x 2 fans

Gas leakage detector
30% LEL: Alarm
40% LEL: Failure

Air inlet
Double wall gas pipe:
Ventilation of 30 times/hour

Master gas valve:
Shut off, in case of 40% LEL
or failure of ventilation fan

Ventilation fan
30 times/hour
50% capacity x 2 fans

Gas leakage detector
30% LEL: Alarm
40% LEL: Failure

Air
Gas supply
Vent

Gas valve unit room
3.4 Project contents (Safety consideration)

- Monitoring of combustion and other conditions
- Double wall gas pipe, Injection of inert gas if necessary
- Ventilation in double wall gas pipe
- Gas leakage monitoring
- Switch over to Diesel mode immediately if necessary
- Prevention of explosion damage
  - (installation of pressure relief valve with flame arrestor)
- Installation of oil mist detector
- Installation of exhaust purge fan after turbocharger
3.5 Project contents (Engine assembly & testing)

- Fuel injection pump
  - For diesel mode
- 2-stage charged air cooler
- Intake bypass valve
- High pressure ratio Turbocharger
Optimized parameter for engine performance

- **Diesel mode**
  - Intake & Exhaust valve timing
  - Fuel injection timing

- **Gas mode**
  - Intake & Exhaust valve timing
  - A/ F-ratio
  - Micropilot injection timing & quantity
  - Differential pressure (gas-boost press.)
4.2 Test results (Operation mode switch)

Switch over from diesel to Gas mode operation

※The following data is slow switch over at 50% engine load.

Switching time: 10s at 25%, 20s at 50%, 30s at 75% engine load
Immediate switch over without fluctuation is possible.

※The following data is during 100% engine load.
Transient response from higher base load for gas mode is restricted by knocking combustion.

Source: CIMAC Gas engine working group position paper 「Transient response behaviour for Gas engine」(2011/4)
This project was carried out with the support of ClassNK as part of the ClassNK Joint R&D for Industry Program.
Thank you very much for your attention!