Development of 4-Stroke Marine Dual fuel engine

(ClassNK joint R&D project)

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July.2014
LNG-Fuelled Vessel Technologies Seminar

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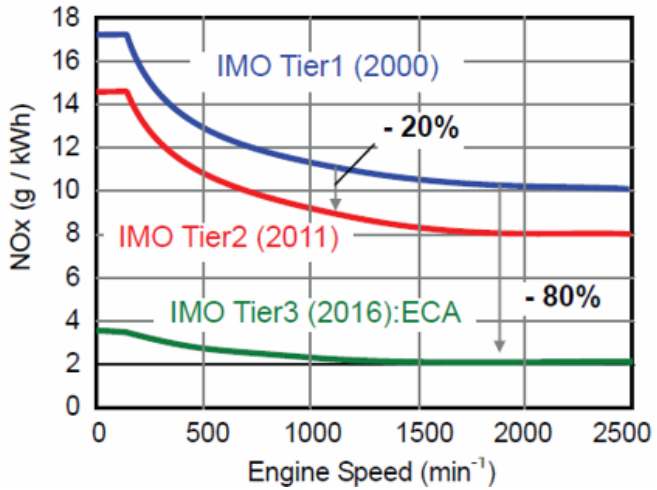
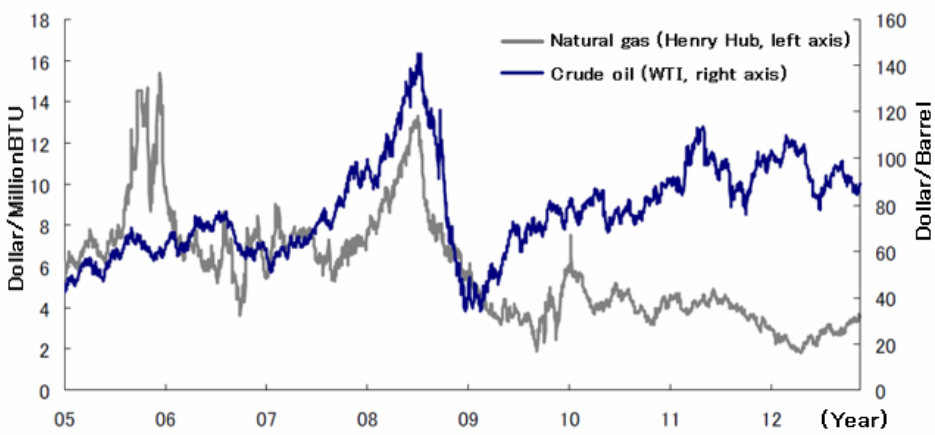
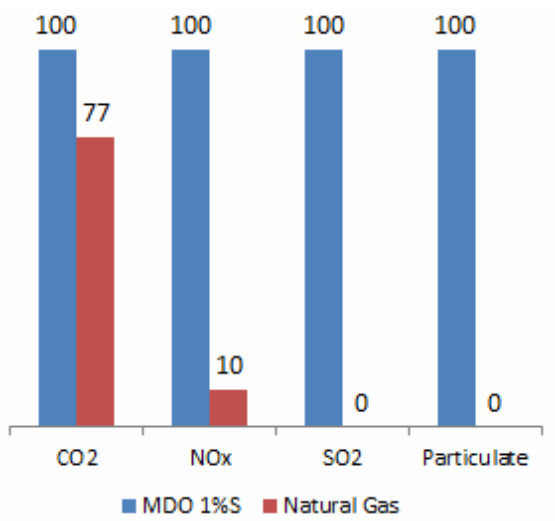
1. Motivation for DF engine development

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





Shift from diesel to DF engine is increasing!



2.1 Project scheme (Project objective)

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- NOx is less than…
  - -TierⅢ limitation by gas mode operation
    （without aftertreatment e.g.SCR）
  - -TierⅡ 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

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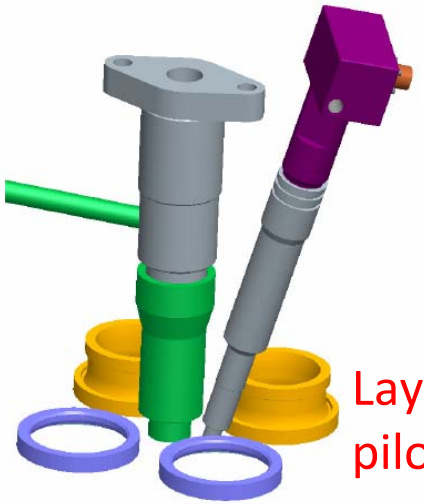
3.1 Project contents (Principal specification)

Bore x Stroke	[mm]	Φ280 x 390
Cylinder No.	[–]	6
Firing order	[–]	1–2–4–6–5–3
Engine speed	[min^{-1}]	720/750
Rated output	[kW]	1,730
BMEP	[MPa]	2.0
Peak firing pressure	[MPa]	17.7
NOx emission	[–]	≦TierⅢ(Gas mode) ≦TierⅡ(Diesel mode)
Main fuel	[–]	Natural gas (Gas mode) MDO,MGO,HFO(Diesel mode)
Pilot fuel (Gas mode)	[–]	MDO or MGO(1% of total heat value)

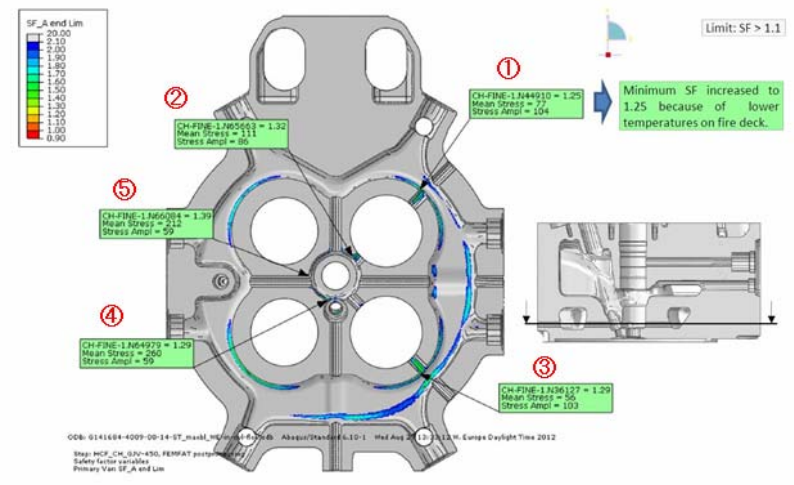
This engine has ***Reliability and durability***, because is converted from DK-28 diesel engine which has many shipments and experiences.

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)

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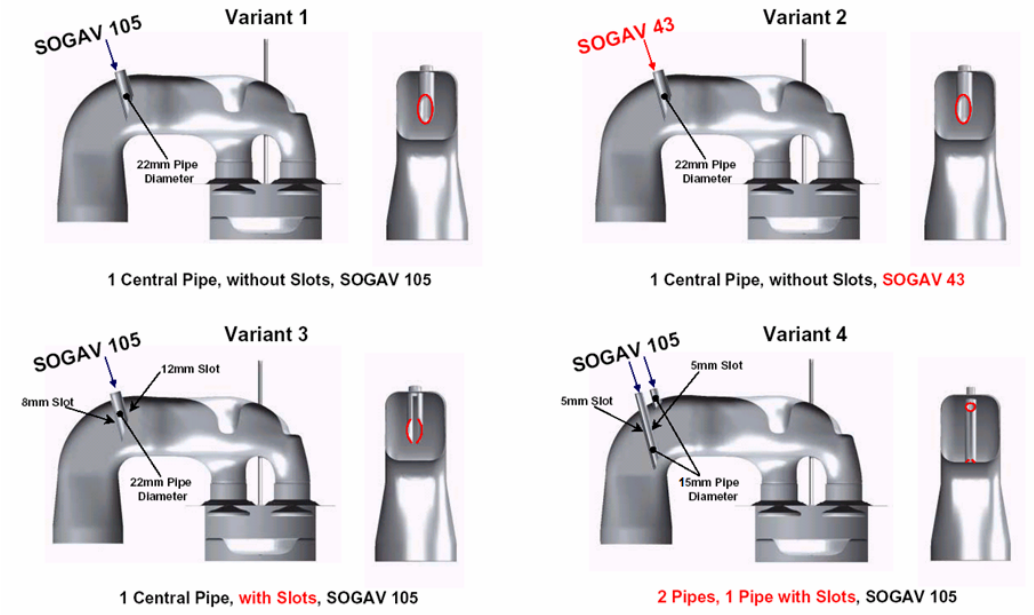
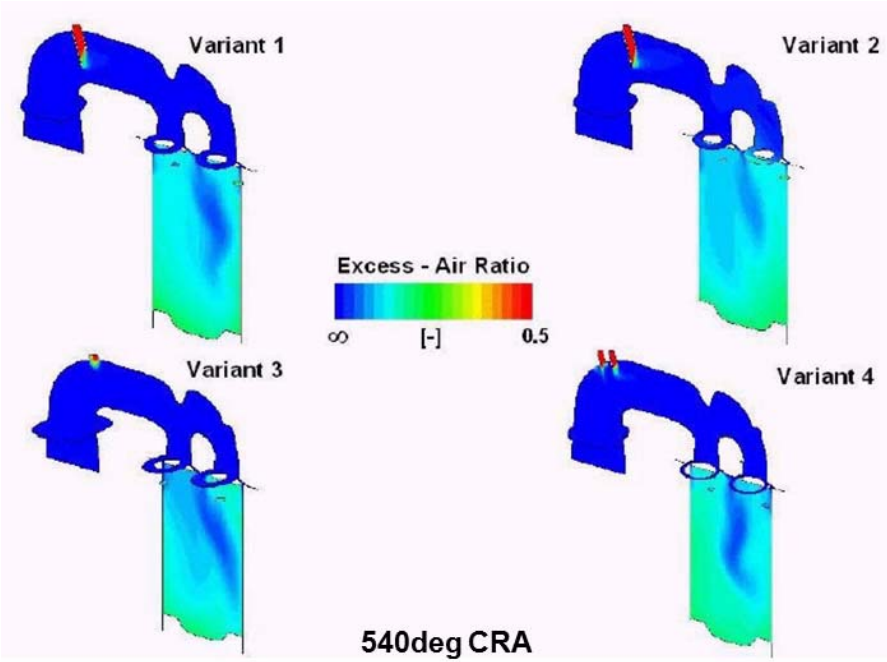
Optimization for mixture formation



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)

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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)

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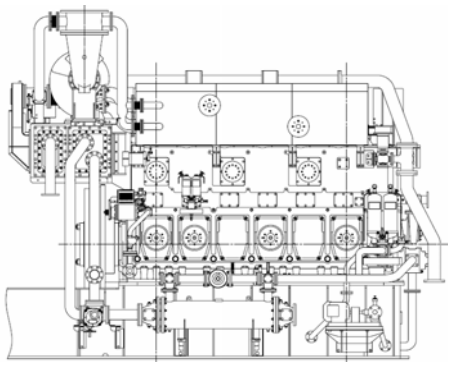
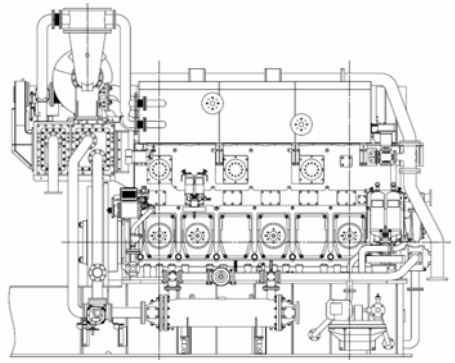
Gas mode



99% ← **Natural gas**
(Test phase: Japan city gas 13A)

1% ← **MDO or MGO**
for Micropilot ignition

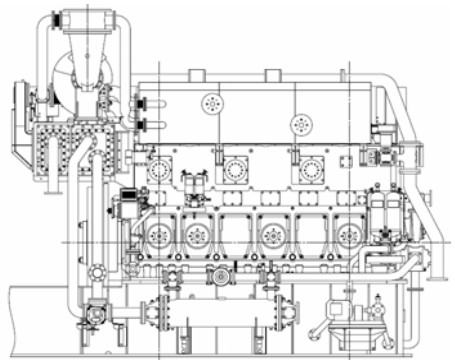
Diesel mode



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

ECS

Detection of knocking

Injector

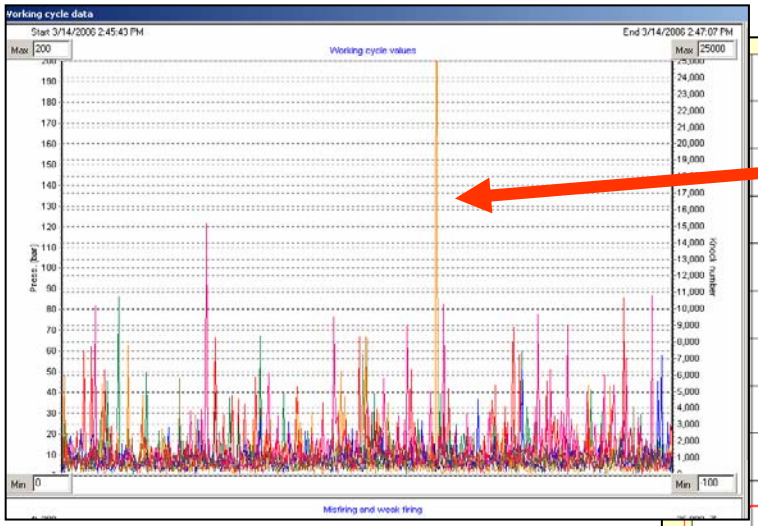
Retard of pilot SOI

Cylinder pressure sensor

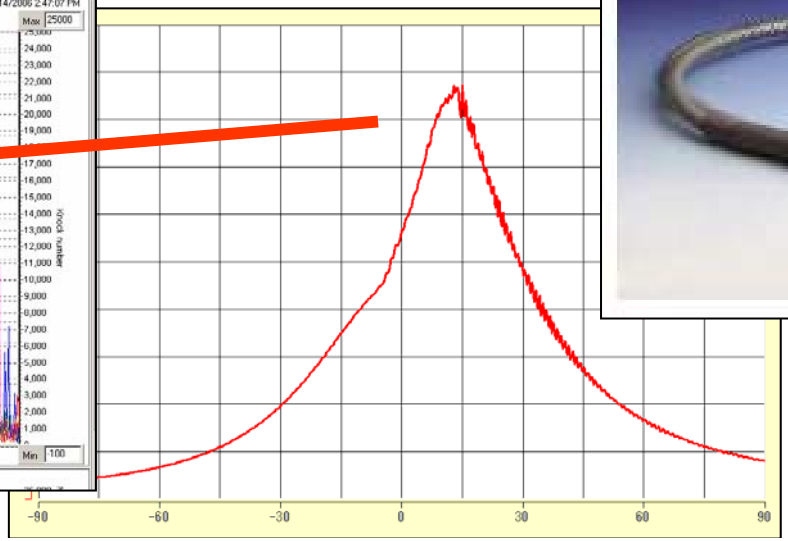
Detection of Cylinder pressure

Data acquisition unit

Calculation of knocking by frequency analysis

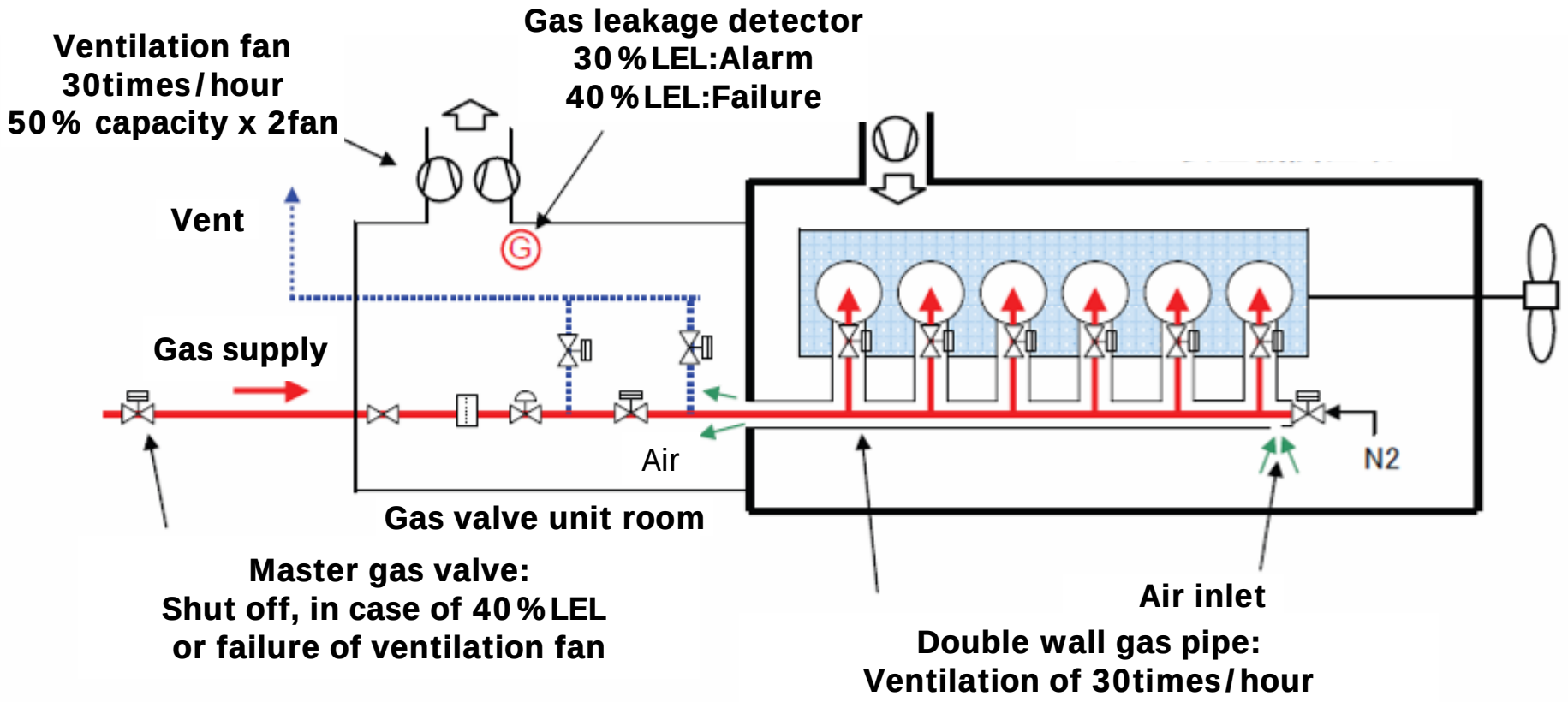


Knocking!



3.4 Project contents (Safety consideration)

Inherently gas safe machinery spaces



3.4 Project contents (Safety consideration)

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- 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)

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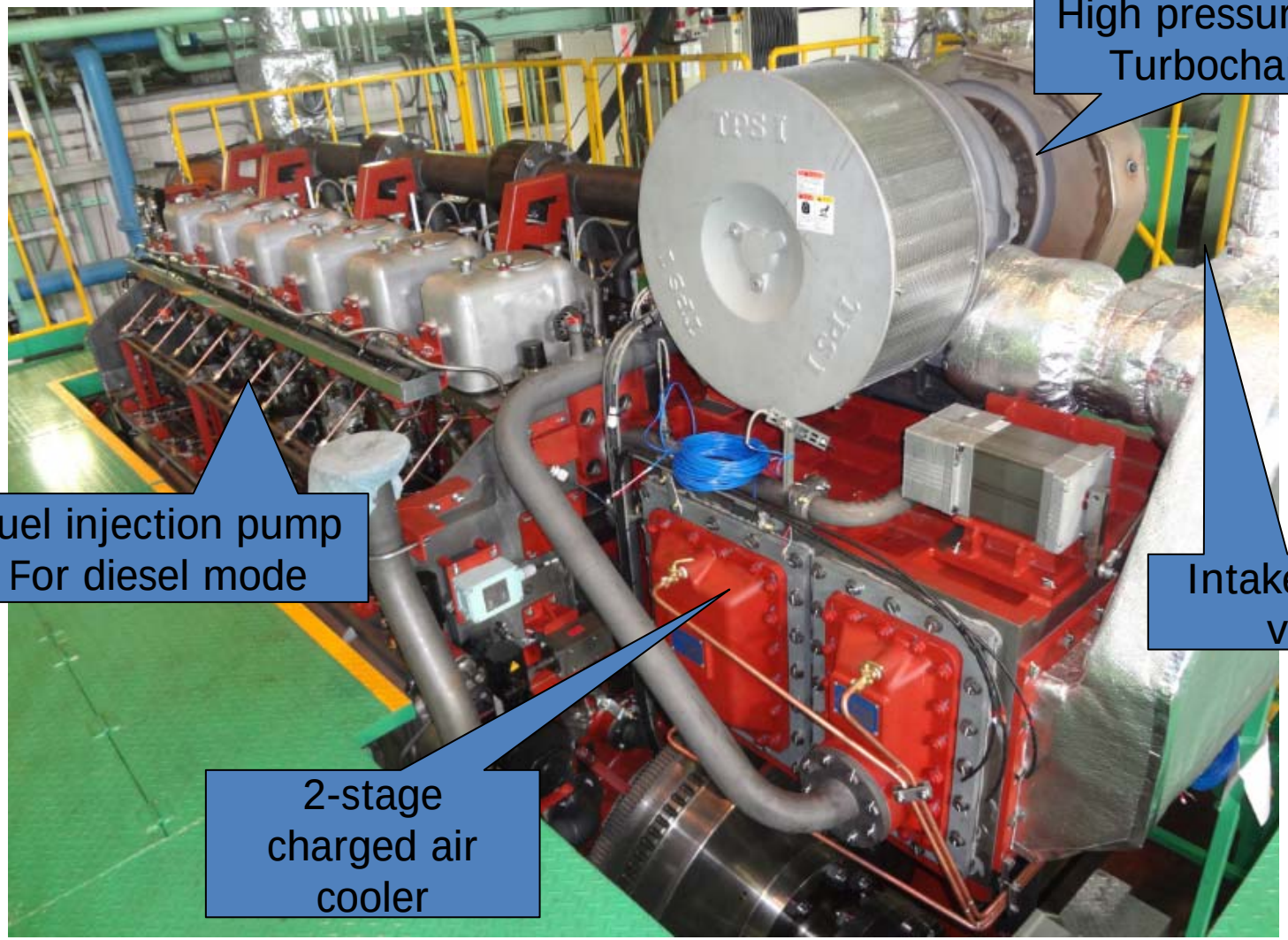

4.1 Test results (Engine performance)

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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)

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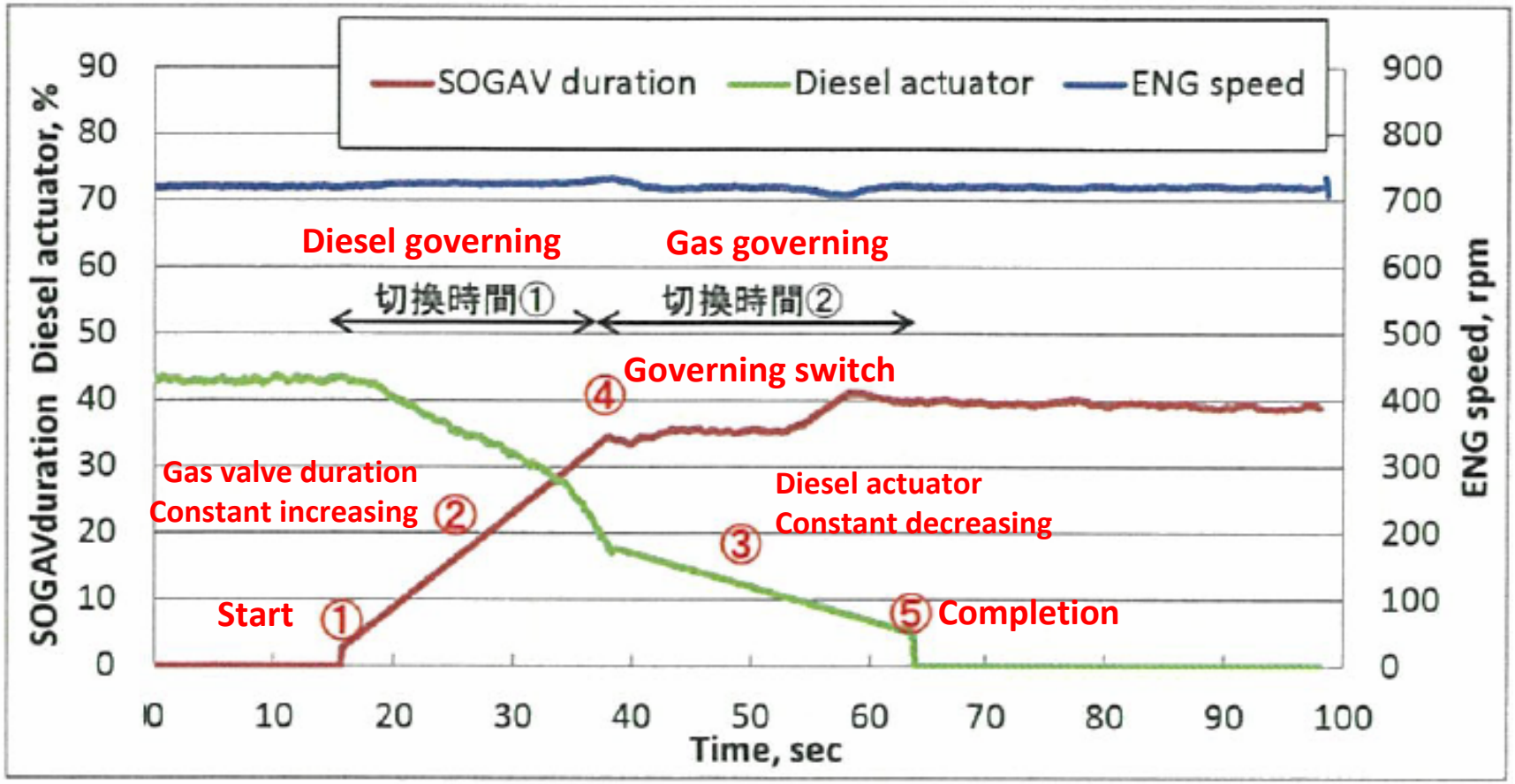
Switch over from diesel to Gas mode operation

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



Switching time: 10s at 25%, 20s at 50%, 30s at 75%engine load

4.2 Test results (Operation mode switch)

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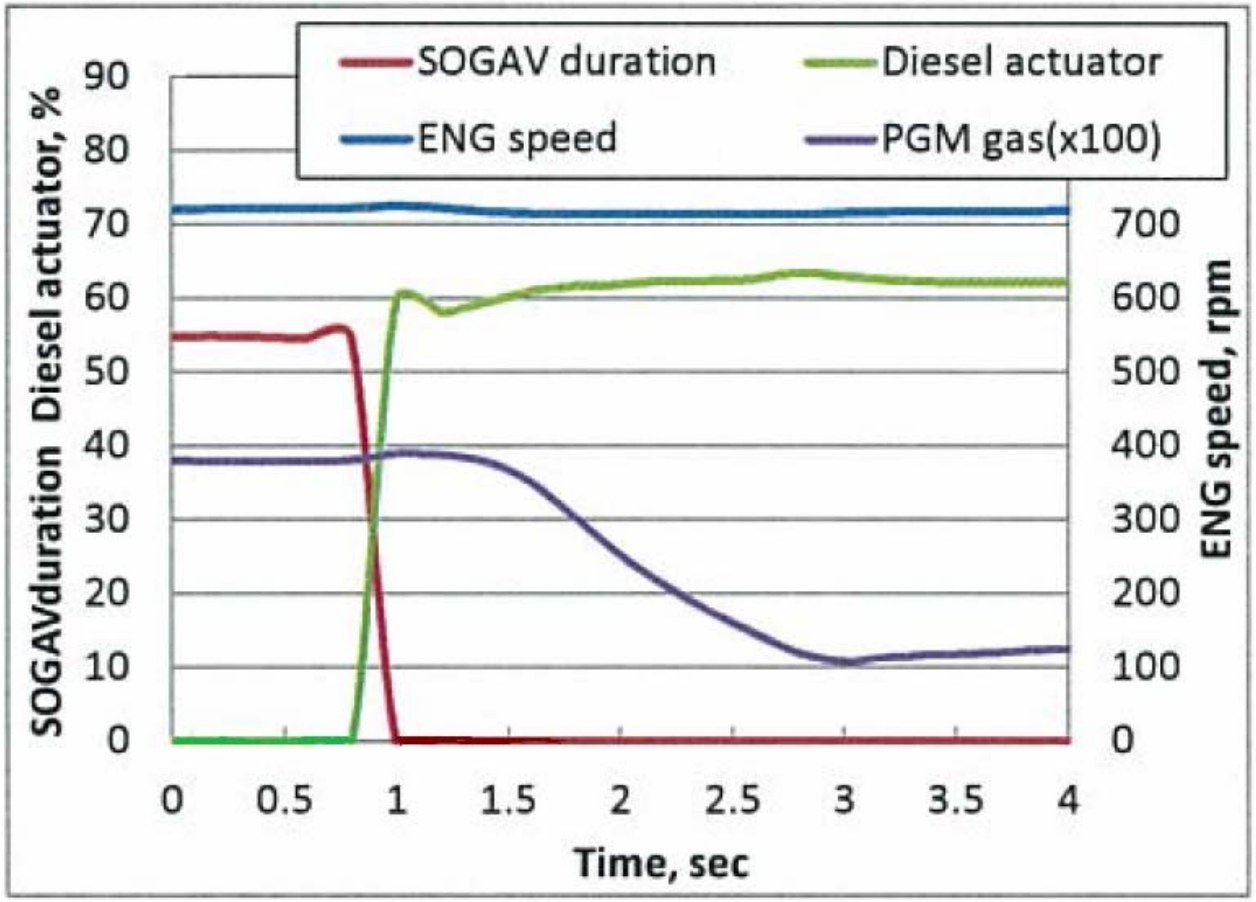
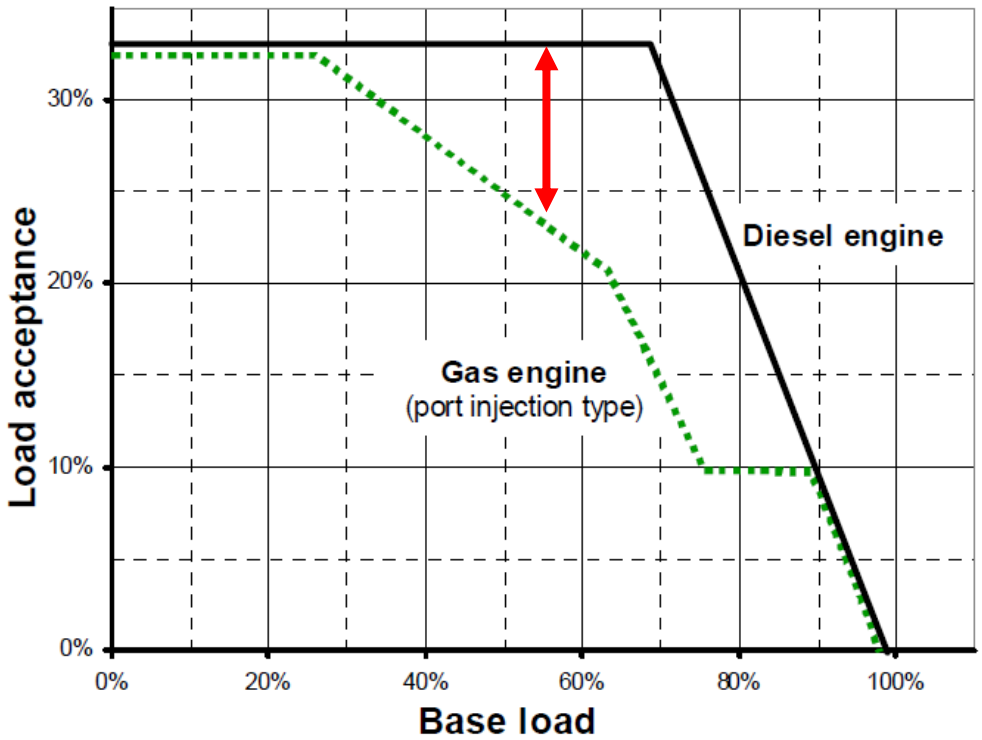
Switch over from gas to diesel mode operation (Immediately)

※The following data is during 100% engine load.



Immediate switch over without fluctuation is possible.

4.3 Test results (Transient response behavior)



Source:CIMAC Gas engine working group position paper
「Transient response behaviour for Gas engine」(2011/4)

Transient response from higher base load for gas mode
is ***restricted by knocking combustion***.

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This project was carried out with the support of ClassNK as part of the ClassNK Joint R&D for Industry Program.

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R&D PROJECT

Thank you very much for your attention!

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