Single Cylinder Engine
– Way forward for future combustion system optimization within Wärtsilä

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Way forward for future combustion system optimization within Wärtsilä

AGENDA

- Wärtsilä in short
- Wärtsilä single cylinder engine (SCE)
- Combustion system development – CFD and SCE combination
- Combustion system development – the future
- Conclusions
Did you know this about Wärtsilä?

Established 1834 in the municipality of Tohmajärvi

Originally a sawmill and iron works company, renamed Wärtsilä Ab in 1898

The first diesel engine saw its day of light in 1942

Nowadays:

Every third ship you see is powered by Wärtsilä

Every second ship you see is serviced by Wärtsilä

One per cent of Global energy is produced by Wärtsilä

“We will be the most valued business partner of all our customers”
R&D development activities are supporting businesses’ focus areas

**Smart Power Generation**
- Products with Fuel flexibility
- Wide spectra with high efficiency
- Fast loading

**Gas as a fuel**
- Further development of DF, GD and SG engine technology for existing portfolio
- Development of new products with high focus on gas

**Environmental solutions**
- Development of SCR, catalysts products integrated on-engine solutions,
- Emission monitoring systems
Wärtsilä R&D footprint

Stord, Norway
Industrial Design

Bermeo, Spain
Engine testing

Trieste, Italy
Engine design & development
Technology Development, Expertise
Research
Engine testing

Vaasa, Finland
Engine design & development
Technology Development, Expertise
Research
Engine testing

Turku, Finland
Engine design & development
Expertise

Espoo, Finland
Research

Drunen, The Netherlands
Research

Winterthur, Switzerland
Technology Development, Expertise, Research

4-stroke R&D ~550 employees of which 410 in Finland
R&D spending 2012: abt. 4% of NS
Continuous strong focus on R&D and life cycle solutions will further strengthen Wärtsilä’s position as technology leader
Medium speed engines portfolio

Power range for medium-speed engines

- Wärtsilä 64
- Wärtsilä 46/46F
- Wärtsilä 50SG
- Wärtsilä 50DF
- Wärtsilä 38
- Wärtsilä 34SG
- Wärtsilä 34DF
- Wärtsilä 32
- Wärtsilä 26
- Wärtsilä 20
- Wärtsilä 20DF
- Auxpac 16

Engine output (MW)
The engine development challenge

How to make a cost effective engines with:

- highest efficiency
- highest power density
- best reliability and flexibility
- fulfilling of future emission standards

Higher efficiency

Higher power density

Combustion system development and a lot of testing is needed ...

Lower Emissions
Single Cylinder Engine (SCE) Testing – Targets and Benefits

• Targets of SCE testing
  – Improve in-house engine performance know-how
  – Dedicated test engine for engine combustion technology development
  – Improve way-of-working; Simulation – SCE – MCE
  – Improved flexibility in testing

• Benefits of SCE testing
  – Be able to test and verify performance in a project pre-study phase
  – Faster in performance concept testing
  – Be cost efficient in engine performance testing
  – Flexible fundamental investigation on combustion concepts
  – Shorter time to market for new products
Wärtsilä SCE – engine, generator, base frame

Height: ~3.5 m

Flywheel: ~5 tons
Engine: ~50 tons
Whole genset: ~75 tons

Main dimensions

<table>
<thead>
<tr>
<th></th>
<th>Tested</th>
<th>Designed</th>
</tr>
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<tbody>
<tr>
<td>Bore</td>
<td>320, 340</td>
<td>260 - 400</td>
</tr>
<tr>
<td>Stroke</td>
<td>400, 430, 530</td>
<td></td>
</tr>
<tr>
<td>Maximum speed</td>
<td>800</td>
<td>860</td>
</tr>
<tr>
<td>Maximum cylinder pressure</td>
<td>315</td>
<td>300</td>
</tr>
<tr>
<td>Fuel types</td>
<td>HFO, LFO, LNG</td>
<td></td>
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</table>
Wärtsilä SCE – engine main parts

- Engine block spacer
- Upper crank case
- Lower crank case
Combustion system development is a very integrated process and collaboration between several parties:

- **Testing** in SCE and MCE (multi-cylinder engine)
- 3-D (CFD), 1-D (GT-Power), and fuel injection (GT-Fuel) **simulation**
- Large bore engine (HFO & gas) **expertise**
- **Test part** design, procurement, **logistics**, and manufacturing
- Engine **controls**

**Combustion system development**

= 

**Increasingly complex process**

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**Good communication is essential**
Combustion development – combining tools gets critical

- Input to model calibrations
- Input for gas exchange in full engine
- Test time optimisation
- Input to model calibrations
- Development of combustion concept available
  - Eventual problem visualisations
  - Future combustion concept research and development

- Spray Combustion Visualization and Research
- Multi-cylinder tests
- CFD / (1D-simulation tool)
- Single cylinder engine
In Otto engines (SG and DF), a flame front propagates through the combustion chamber and consumes the premixed charge, leaving combustion products (and pollutants) behind.

Since 2010, we have been able to simulate single-fuel (SG) natural gas combustion with good accuracy!

Improvement mainly thanks to improved chemistry!
Flame front propagation in a W34SG engine

- A small, centrally located pre-chamber is fed with extra gas to make the local mixture possible to ignite by means of a conventional spark plug
- The pre-chamber combustion sets up the flame front for the main combustion chamber but also produces strong jets
- These jets give the flame front an unusual shape and a behaviour that also has similarities to a diesel flame
DF engine combustion modelling challenges

- A small diesel flame ignites the gas charge since liquid fuel has better ignitability than the very lean (λ=2.1) gas/air mixture
- The pilot injection is only ~0.5% of the total fuel energy and spray penetration is short
- Until recently, simulating pilot-ignited gas combustion has not been possible (only single-fuel combustion models)
- In STAR-CD v4.18, the use of two fuels is possible and initial results are promising
- Another approach being benchmarked is to solve for the detailed chemistry directly during the CFD simulation
  - CFD software CONVERGE
  - FORTE
  - PVM combustion model soon to be released for STAR-CD
- All these methods require chemistry-based input for accurate results
- Acquiring, testing, and validating chemistry mechanisms and chemistry-based inputs for realistic fuels is an important focus area in the current method development efforts
Along with the fuel injection system specifications, the combustion chamber geometry determines how the flame develops after it impinges on solid surfaces.

The interaction between the flame and the combustion chamber surfaces, as well as between the flames of the individual sprays, has a strong effect on the combustion and emissions.

Understanding and optimising these interactions is a core concern in current combustion system development – for this we need CFD simulations!
The use of modeFRONTIER for DoE, simulation control, and advanced result analysis is already commonplace for diesel combustion work.

Typically, computational meshes are pre-generated but modeFRONTIER controls all other input parameters ranging from fuel injection timing and nozzle specification to EGR rates and Miller timing.

modeFRONTIER generates a simulation matrix using DoE techniques and launches it. The CFD results are post-processed using response surface modelling to identify optimum designs even if not yet simulated.
A parametric combustion chamber profile was defined, allowing a large set of combustion chamber shapes to be generated automatically.

Coupled with previously developed template-based meshing tools, this enabled fully automatic meshing of sector models.

For SG engine applications, the tools were extended to include automatic variation of the nozzle hole size, number, and angle.

Simulations set up, run, and post-processed by the optimisation software modeFRONTIER.
Optical measurement methods

- Single-cylinder test engine (SCE)
  - Optical access components have been developed for the SCE in Vaasa
  - With the engine configured as a gas engine, passive imaging tests have been carried out
  - Using LIF with acetone as a tracer has been studied for visualisation of fuel depletion
  - IMPORTANT INPUT FOR CFD MODEL DEVELOPMENT
- Collaboration with Lund Technical University
Optical measurement methods

- Spray combustion chamber (SCC).
  - Developed during the EU projects I.P. HERCULES and HERCULES β
  - Many reacting and non-reacting shadow imaging studies performed, e.g. for CFD modelling input
  - Mie scattering investigations enable nozzle geometry effects to be studied
  - PDA tests used to study droplet sizes and velocities (evaporation)
  - Spray + ignition + soot studied by means of simultaneously applied shadow-imaging, chemiluminescence and incandescence

The SCC test facility in Winterthur.

Combusting HFO sprays.

Mie scattering tests.

CFD model validation

T(x,t)
S(t)

x = 30 / ... / 75 / 90 x d₀

"lower" ("luv")
"upper" ("lee")

spray cone angles ϕ(x,t) at
x/d₀ = 30 / ... / 75 / 90 nozzle diameter distance

spray penetration S(t)
dense core
spray contour
Combustion control for future gas engines

Combustion Control
- Pro-active and adaptive control methods
- Abnormal combustion and lambda control
- Sensor technologies

Combustion Modeling
- CFD modeling of abnormal combustion phenomena’s
- From a control perspective

Actuator Development
- Pre-chambers, injectors, gas admission valves, spark plugs, wastegate, VIC, etc.
- From a control perspective
Conclusions

- Utilization of best available research institutes and universities for basic research and expertise is even more needed in the future.
- Pre-screening of potential technologies on dedicated research engines (Multi-cylinder – MCE & Single-cylinder engines – SCE).
- More resources on CFD simulation for pre-optimization and proper input to design.
- Shorter engine development iteration loop, due to:
  - Dedicated performance SCE’s
  - Functionality engine rigs
  - Working logistics
- Verification of developed combustion systems in prototype MCE’s. About 80% of performance development in beforehand on SCE’s.
Conclusions

Shorter product development time is crucial for future competitiveness!

Together with skilled partners and utilising new tools like the SCE we can make a difference!