Development of enabling technologies for efficient use of green hydrogen in ICEs

Giornata di studio AIMSEA

Genova, 25 Gennaio 2024

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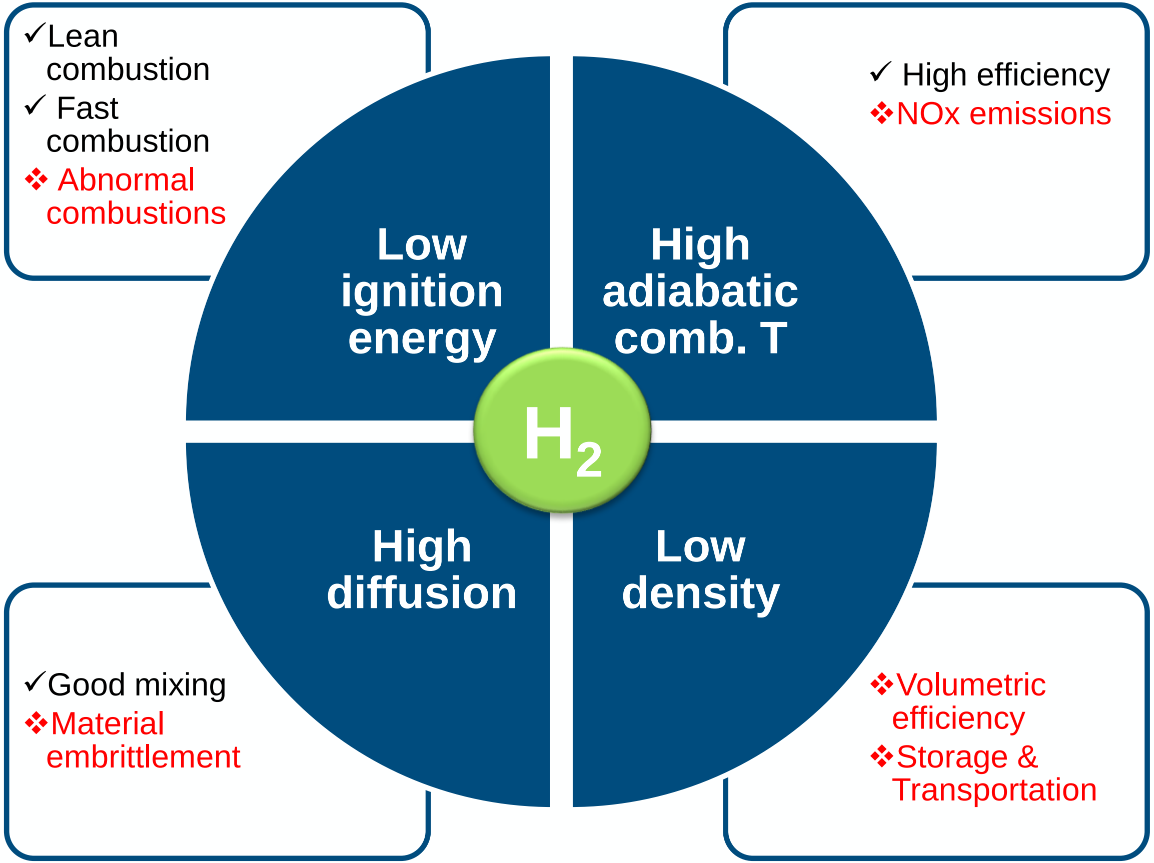

✓Lean combustion
✓ Fast combustion
❖ Abnormal combustions
✓ High efficiency
❖NOx emissions
Low ignition energy
High adiabatic comb. T
H_2
High diffusion
Low density
✓Good mixing
❖Material embrittlement
❖Volumetric efficiency
❖Storage & Transportation

Development of a real-time control system

Target

Real-time control for prevention of **abnormal combustion** events

- **AFR and iEGR** real-time/transient estimation
- ECU implementation

Joint collaboration supported by Yanmar R&D Europe

Methodology & steps

Real-time SIMULINK model

models calibrated/corrected with GTPower Three Pressure Analysis (TPA) for AFR and iEGR real-time/transient estimation

Assessment on experimental data

H2-fueled PFI engine

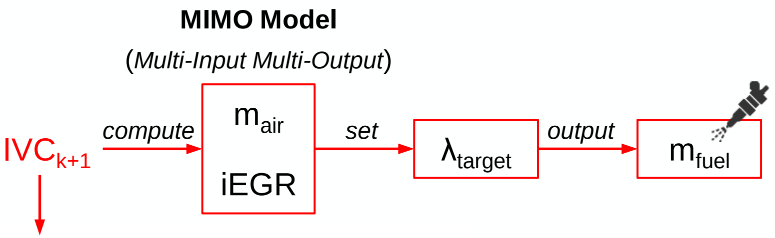
dSPACE HiL system

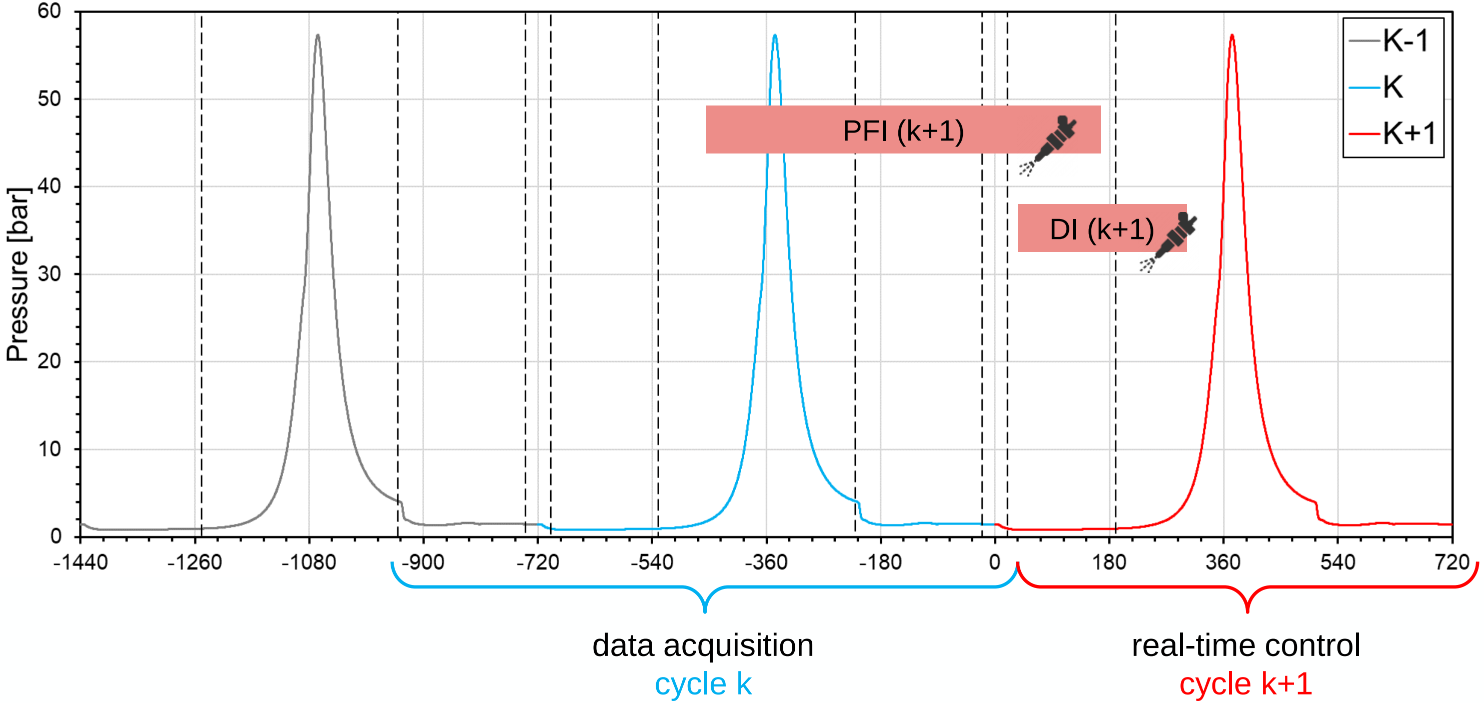
Implementation of the numerical model on prototype control system

Final experimental assessment

Experimental assessment of the control system (stationary and transient) on a H2DI-engine (@ the test bench)

Real-time AC+iEGR





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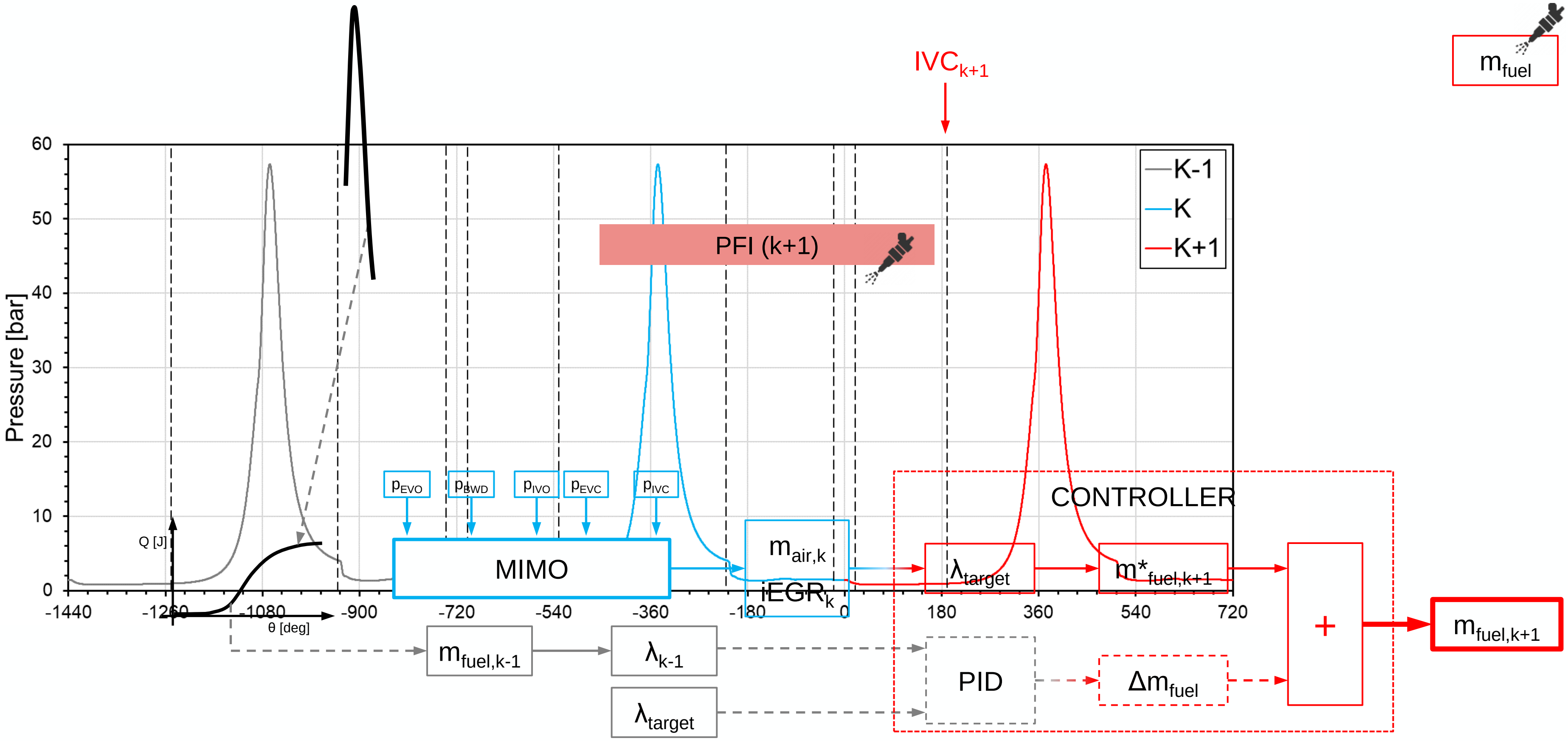
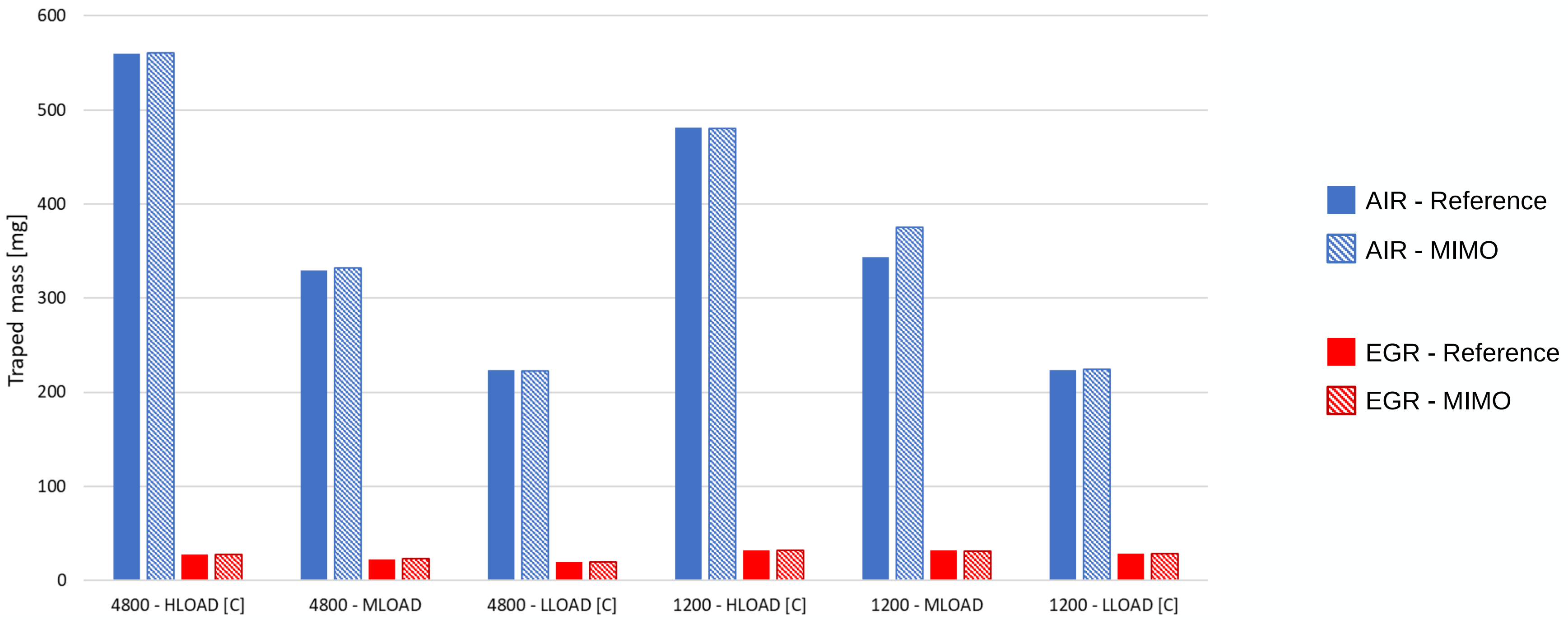
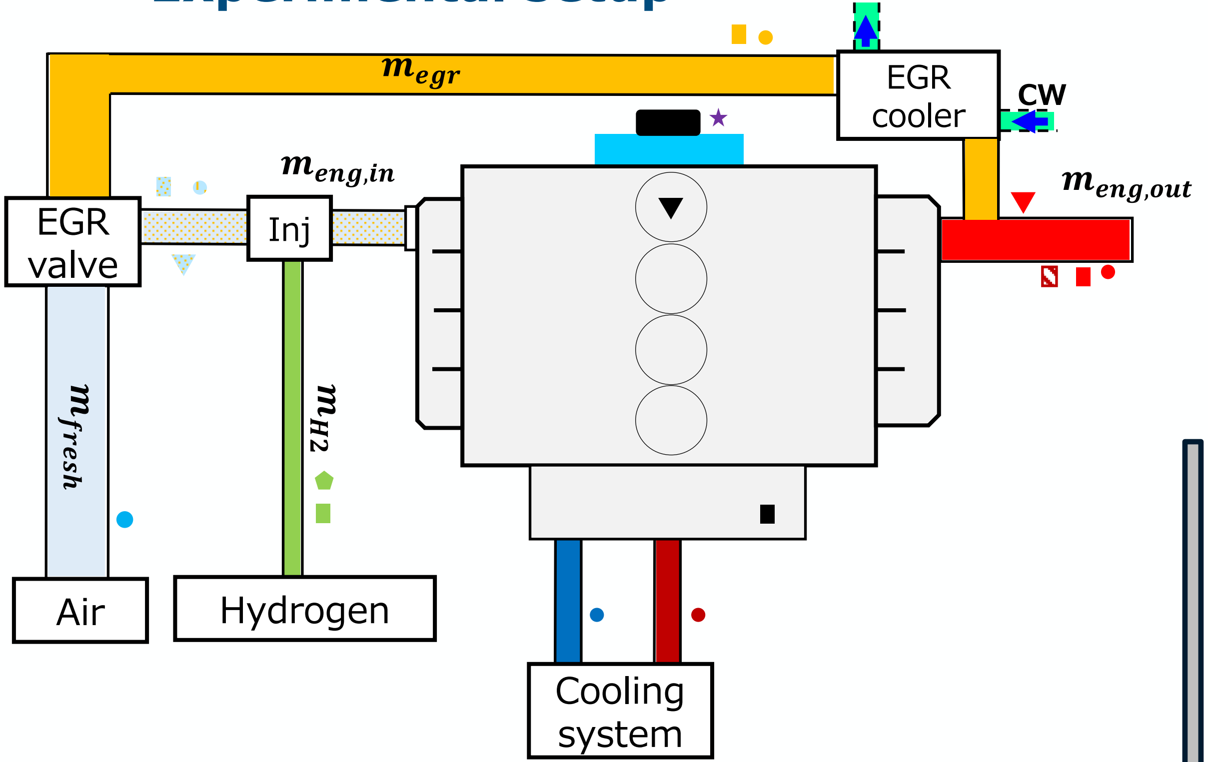
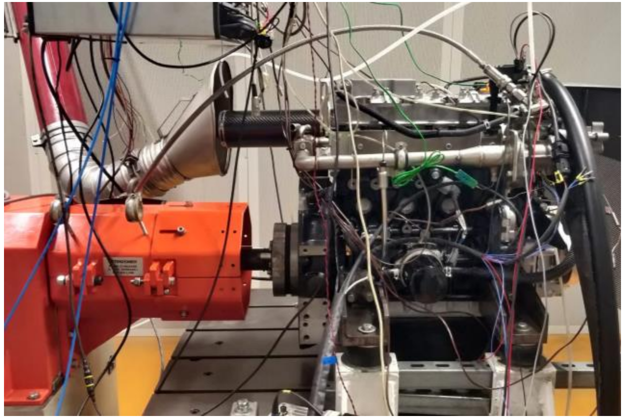


Calibration and Validation



Experimental setup





Sensors list

- Exhaust T.
- Air T.
- EGR T.
- Intake T.
- Water in T
- Water out T.
- Exhaust P.
- Intake P.
- EGR P.
- Hydrogen P.
- Lambda sensor
- In-cylinder dynamic pressure
- Exhaust dynamic pressure
- Intake dynamic pressure
- Hydrogen mass flow
- Torque-meter

Hydrogen supply setup

H2 produced by electrolizer

- Working on demand (no storages)
- H2 max Flow rate 14 m^3/h (1,26 kg/h, 33 kWt)

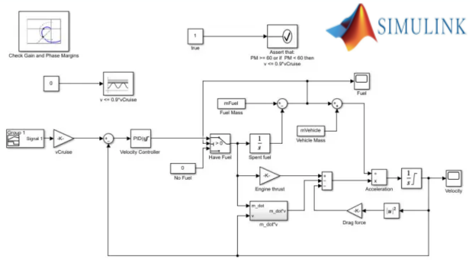
Safety management

- Huge amount of diluition air, on the electrolizer and in cell, H2 less than 3%
- Air flow meter in the safety ring
- H2 sniffers

Hil testing – dSPACE

Analog signals

dSPACE MABIII



PREDICTIVE MODEL

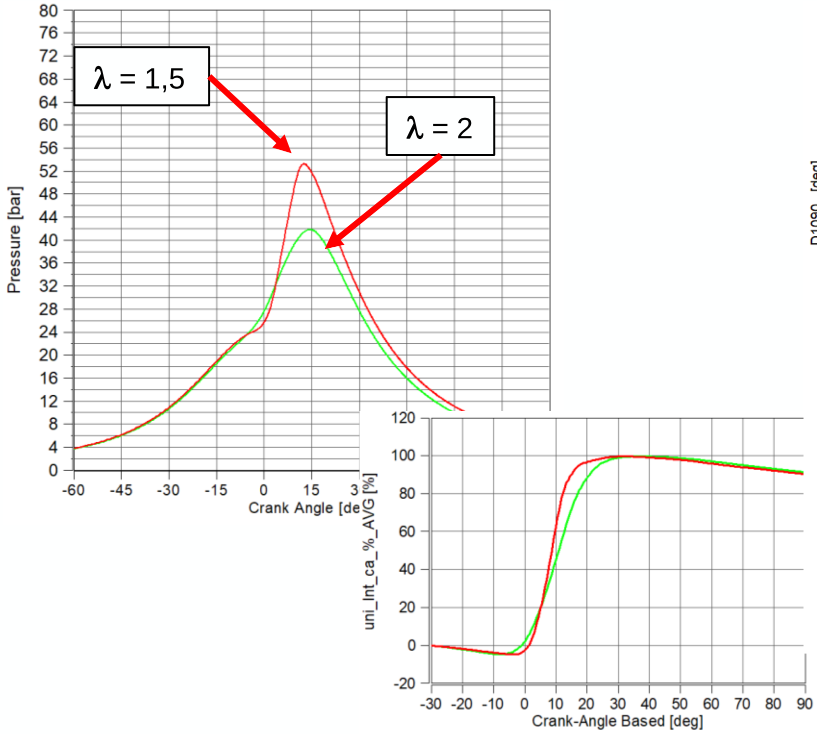
Engine Sensors signals

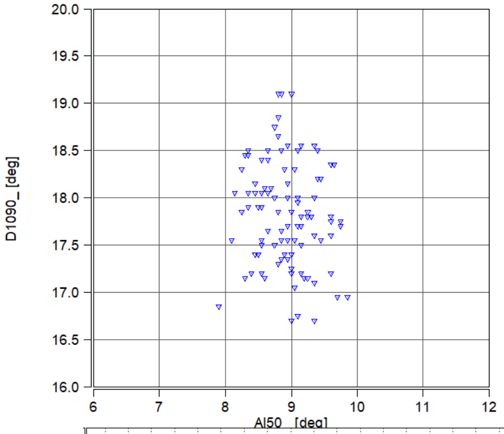
-Start Of Injection (SOI)
-End Of Injection (EOI)

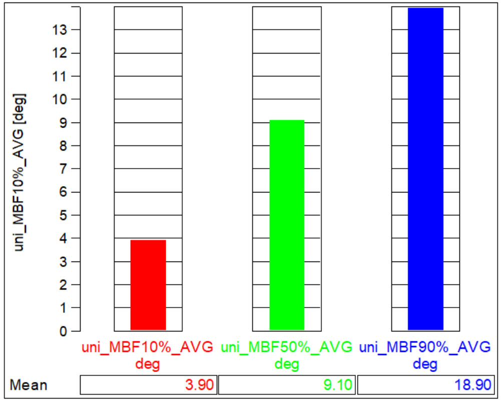
-Spark timing

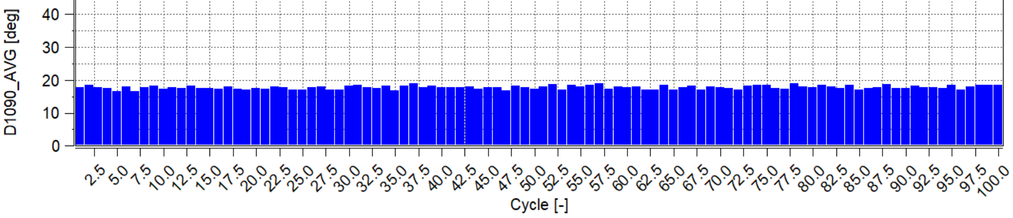
-EGR valve status

Preliminary results on experiments



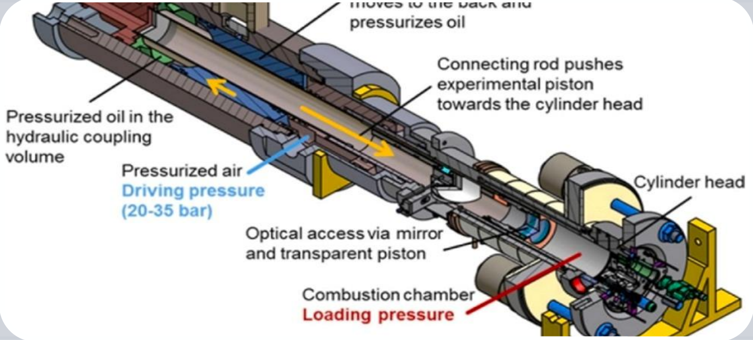


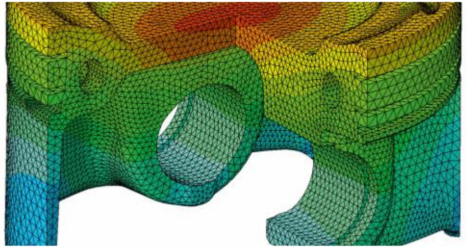




λ = 1,5

Developments in progress on H2 ICE





RCEM

Complete investigation of combustion phenomena:

repeatability

controlled thermodynamic conditions in cc

covering all the processes from ignition to combustion

TISMEN

Funded project (accordi per l'Innovazione – MIMIT)

Partner:

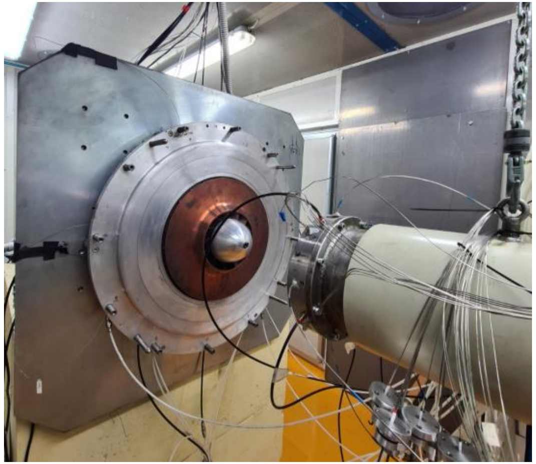
ASSO WERKE

PONTLAB

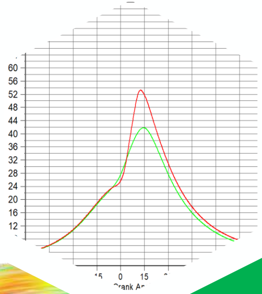
UniPI

UniFI

Many aspects to be addressed and faced by REASE research group

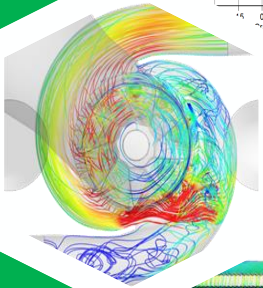


ICEs



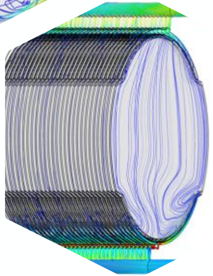
Numerical & experimental

Centrifugal & reciprocating compressors



Compression

H2 production



Electrolizers Numerical & experimental development

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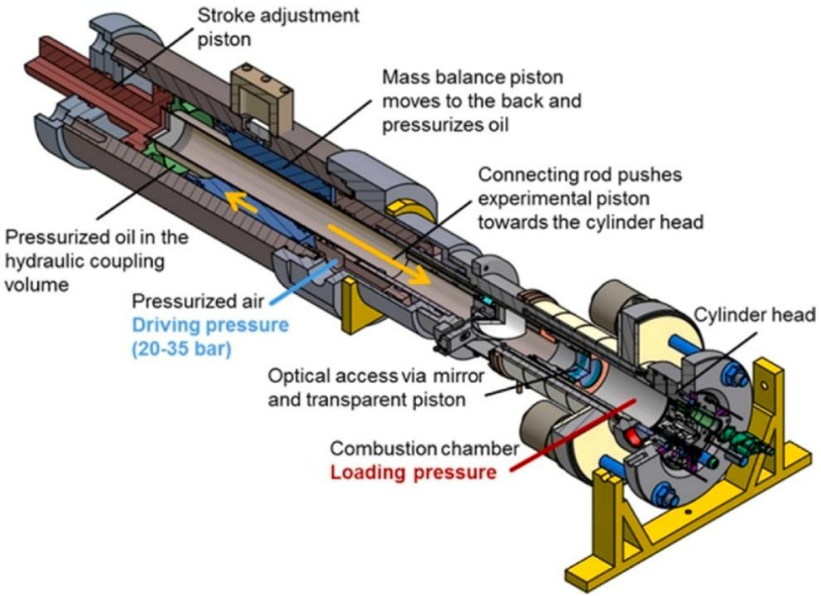
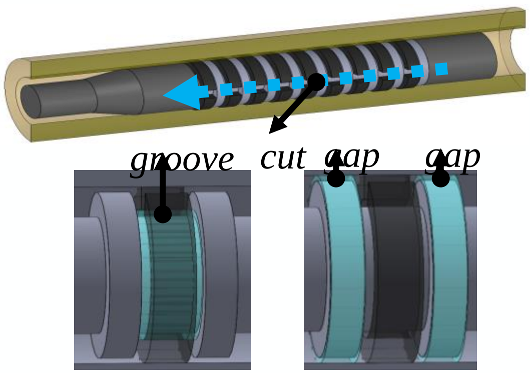
RCEM (Rapid Compression Expansion Machine)

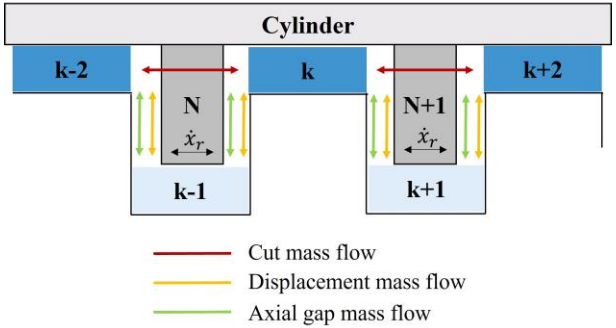
Complete investigation of combustion phenomena in ICE:

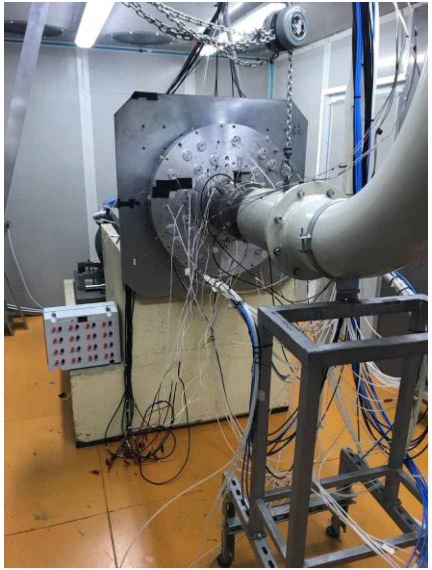
- repeatability
- controlled thermodynamic conditions in cc
- covering all the processes from ignition to combustion

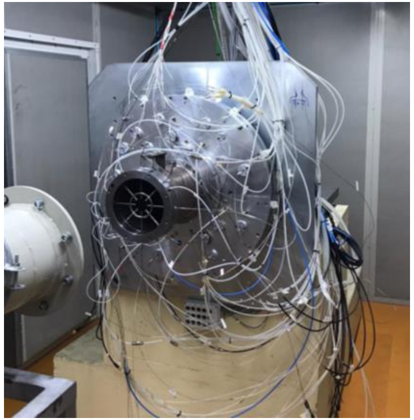


T Kammermann et al., SAE Int. J. Engines / Volume 10, Issue 4 (October 2017)


groove
cut
gap
gap


Cylinder
k-2
k
k+2
N
N+1
k-1
k+1
Cut mass flow
Displacement mass flow
Axial gap mass flow





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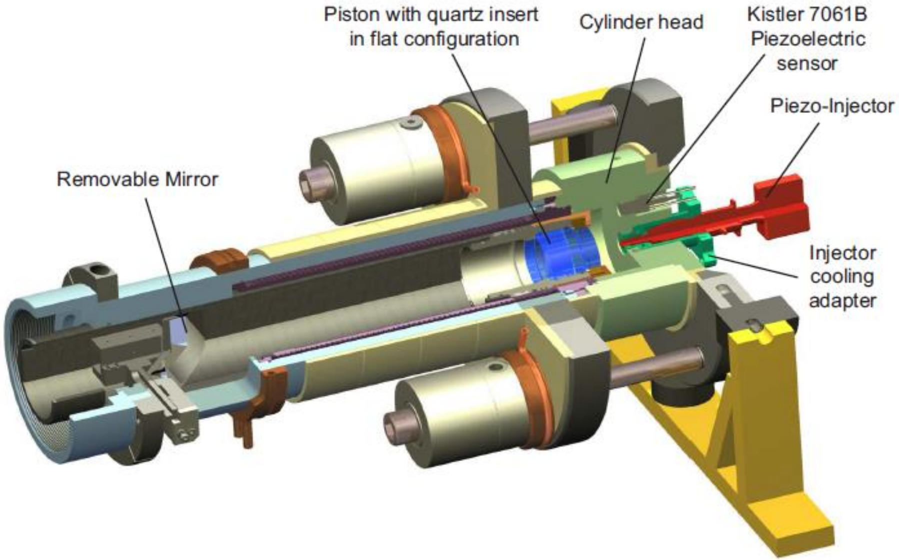
RCEM (Rapid Compression Expansion Machine)

Versatility of investigation thanks to:

- Possibility to modify piston and head geometry, injection system
- 3 optical accesses (piston + 2 in the CC)

Same advantages of transparent engines, but also:

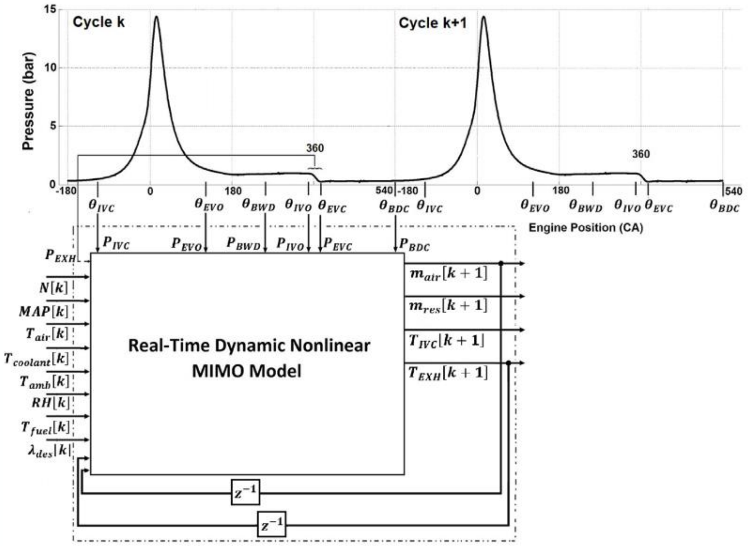
- No vibrations
- Easier optical access
- CC operating conditions adjustable



Real-time AC+iEGR

Numerical Model main characteristics
(Based on Khameneian et al. doi.org/10.1016/j.conengprac.2021.104978)

- **Real time** calculation of **AC** & **iEGR** for fuel & combustion control
  - Gasoline GDI SI engine
  - **AFR transient** control (with validation)
- **Physics based** model (Simulink/Stateflow)
  - Possibility of extension for further aspects (extEGR)
  - 2 strictly dependent submodels (Air Charge and iEGR)
- Minimal **calibration** (2 coefficients, lookup tables)
  - Done with **GT Power TPA**, @Steady state
- Corresponding **experimental setup**
  - In-cyl pressure sensor
  - Intake LFE
  - Intake MAP/Temperature sensor
  - Exhaust pressure and lambda sensor



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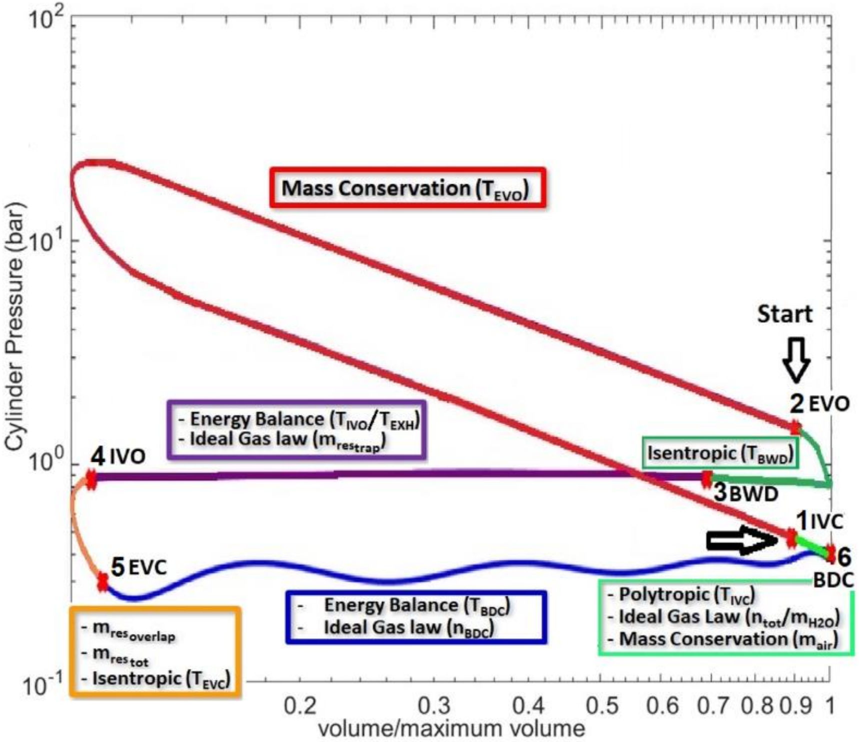
Real-time AC+iEGR

New implementations needed for different case study

- **PFI vs GDI**:
  - Change in **(5-6) energy balance**: no fuel vaporizati
    - Mixing equation in (3-4)
    - T_{FUEL}, m_{FUEL}
- **H_2 vs Gasoline**: chemical tuning
- **External EGR**: additional mixing equation
  - $T_{EXT\ EGR}$, $m_{EXT\ EGR}$

2



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Hydrogen supply setup