Investigation on the usage of alternative fuels and hydrogen in high-performance internal combustion engines with CFD approach

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ABSTRACT

The decarbonization of the transportation sector passes through the substitution of fossil fuels in favor of renewable sources, such as bio-fuels and hydrogen. However, in the meanwhile, a great contribution to this strategy is represented by the increment of engine efficiency. Under this aspect, it must be considered that, especially for SI engines, the most influencing engine parameter is the volumetric compression ratio; therefore a large research is carried out around the world trying to increment it as much as possible. Unfortunately, increasing the compression ratio of the engine, not only the efficiency, but also the tendency to detonation (knocking) is increased, with disastrous effects on engine durability. Knocking is characterized by complex chemical-physical phenomena and a wide research activity is conducted in the last years trying to better understand all the mechanisms involved. One of the main parameters involved is the fuel's knock-resistance, and the engine's performance depends directly on it. This study is aimed at the development of a method that allows to predict the knocking behavior of an engine given the geometry of the combustion chamber, the chemical composition of the fuel, and the boundary conditions on which the engine is operating (such as load, rpm, etc). The project firstly outlines in the development of a numeric model built on the basis of experimental data taken under knocking conditions. This model allows to predict the engine's behavior. Then, the model will be upgraded to a CFD-3D case, which allows to achieve the heat map on the piston crown, a useful information for high-performance engines.

Keywords: engine, knock, model, fuel, alternative, hydrogen, CFD

INTRODUCTION

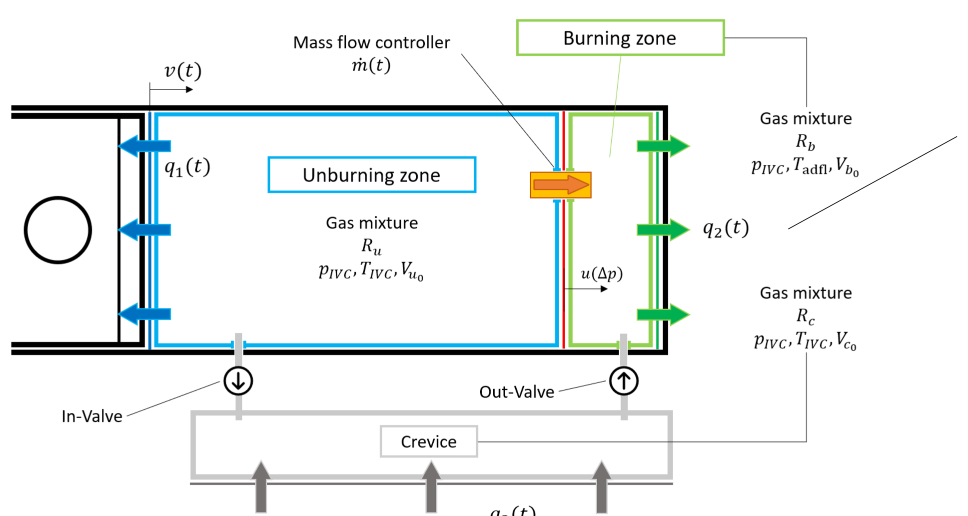
Nowadays, the fight against climate change enforces a progressive abandonment of the internal combustion engine (ICE); on the other hand, an abrupt switch to a total electrification of vehicles is still unattainable. In addition to that, there are some applications that still require an ICE, thanks to its reliability. For these reasons, engines's sustainability must be improved more and more in order to operate green. This concerns the usage of alternative and carbon-free fuels, such as e-fuels and hydrogen.

It seems reasonable to assume that, even on the usage of alternative fuels, engines should work in high-efficiency conditions. This study arises from the need to broaden knowledge about the behavior under the usage of different fuels, especially in high-performance engines.

The main project starts with the development of a numeric model that is able to reproduce the engine's behavior by simulating the pressure trend on the basis of a set of experimental data. By switching the geometry of the combustion chamber, the chemical composition of the mixture, the operating conditions, the model is able to predict the engine's behavior in different conditions.

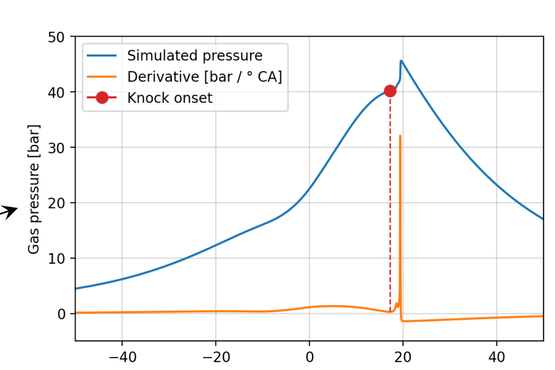
FIRST ACTIVITIES

During the first period of the first year of the PhD the candidate has been involved in the definition and a first development of the numeric model.



- Reactors with chemical reactions;
- Mass exchanges between reactors simulate the combustion;
- A pressure-drop moving wall simulates the expanding flame front;
- Thermal exchanges between reactors and engine's walls.

The model is able to simulate a pressure cycle



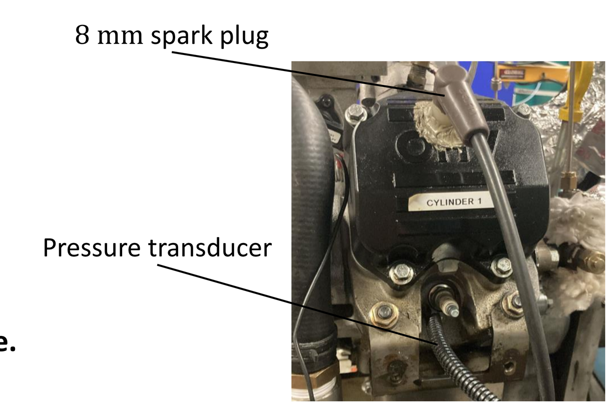
PERIOD ABROAD - LABORATORY EXPERIENCE

From March until September the candidate spent six months as a period abroad at the University of Wisconsin-Madison. During the time spent at the UWM, the candidate worked in a laboratory of the Engine Research Center. The work consisted in collecting sets of data under knocking conditions with a specific fuel, to further develop the numeric model.
The engine was a 2-cylinder Kohler Aegis LH775 with modifications on both cylinders's head that allowed to put pressure transducers inside the combustion chambers. Another modification on a piston's head allowed to reach a different compression ratio in one cylinder.

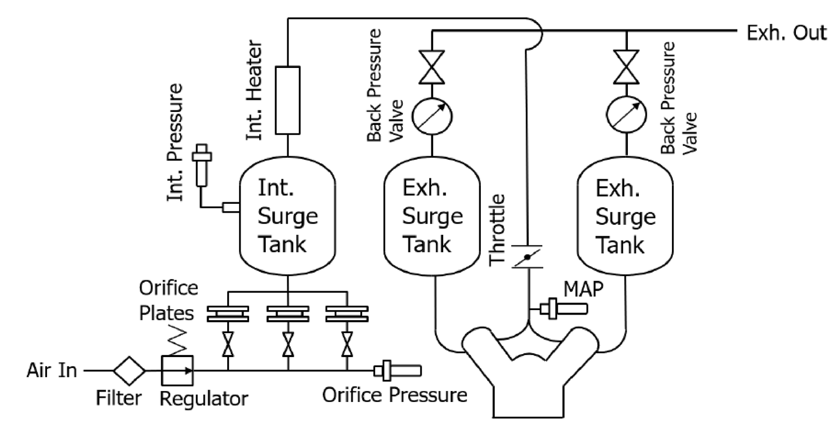
Engine's specifications

Make/Model	Kohler Aegis LH775
Cyliders	2
Bore [mm]	83
Stroke [mm]	69
Rod length [mm]	114
Totla displacement [mm]	747
Geometric CR	8.7
Modified CR (only cylinder 1)	10.2
Rated speed [rpm]	3600
Rated power [kW]	21
EVO [°bTDC]	-130
IVO [°bTDC]	-338
EVC [°bTDC]	334
IVC [°bTDC]	134

The Kohler Aegis LH775 engine.



Spark plug's and transducer's locations.



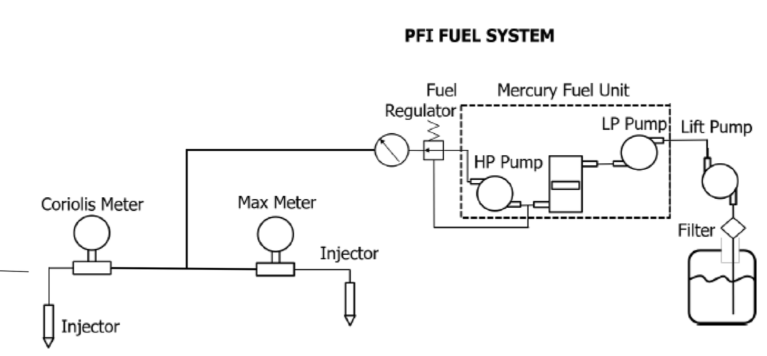
A particular air supply system allows to take data while the engine is breathing at constant intake pressure and temperature, and between a constant pressure drop, to ensure that the ambient variables do not influence on the operating conditions.

Transducers's specifications

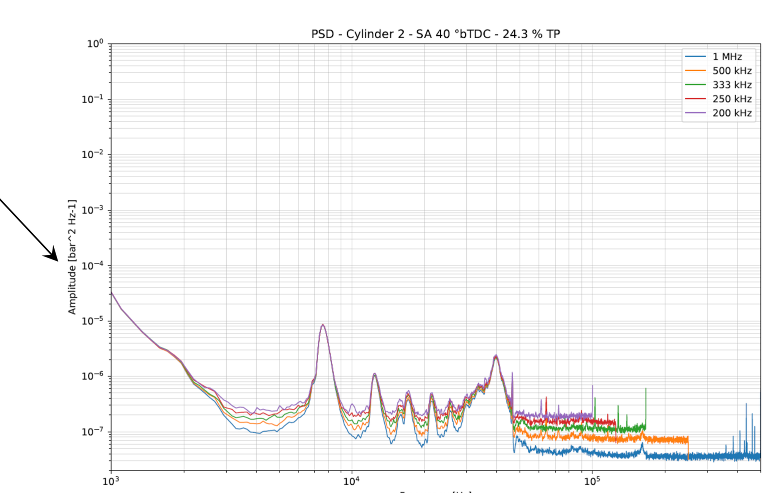
Make/Model	AVL GH14DK	KISTLER 6052C
Measuring range [bar]	0 ÷ 300	0 ÷ 250
Operating temperature [°C]	−40 ÷ 400	−20 ÷ 350
Natural frequency [kHz]	≃ 170	≃ 160

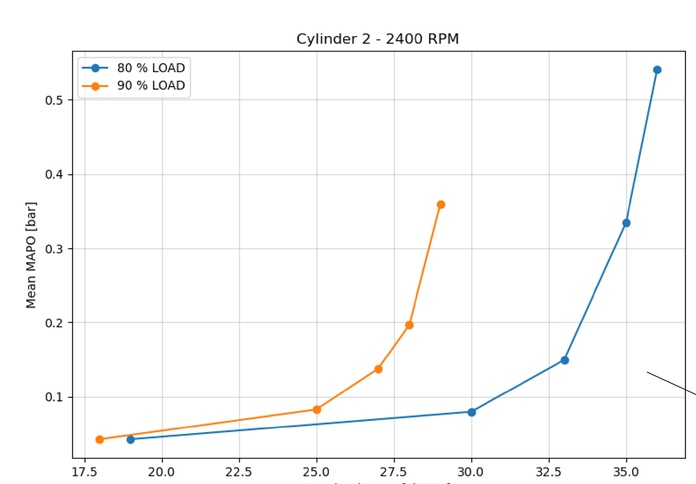
The pressure transducers have been choosen thanks to their natural frequency higher than the knock-characteristic frequencies.

A particular fuel supply system allows to take data by knowing the exact fuel mass flow rate that feeds each cylinder.



Some parameters related to the signal processing such as the sampling frequency, have been choosen during the experimentation.

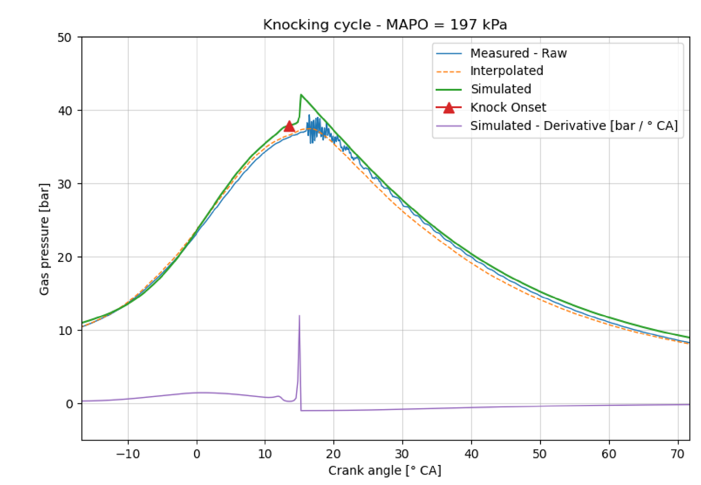




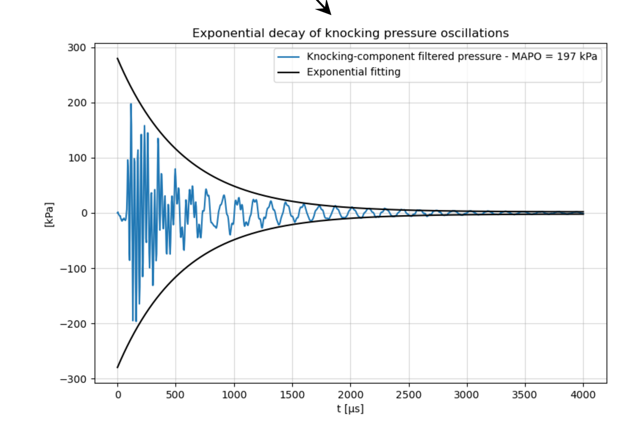
During the experimentation, knocking conditions were induced by acting on the spark ignition advance values in both cylinders.

PRELIMINARY RESULTS AND NEXT ACHIEVEMENTS

Once the sets of data of interest were collected, the model has been calibrated and simulations were run to reproduce the engine's behavior under the same operating conditions.



A different knock intensity index based on the exponential envelope of the pressure oscillations will be used.



The model allows to know the crank angle location of the kncok onset, and consequently the unburnt mass at that time: this information will be used to define a relation between the knock intensity and the mass at KO.

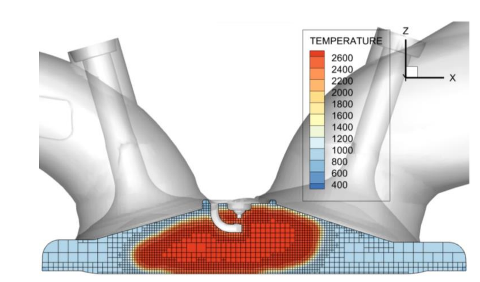
TRAINEESHIP PERIOD – LEARNING CONVERGE

From October until now the candidate has started a traineeship at Asso Werke srl, a company that produces pistons for high-performance engines. The traineeship aims at learning to use Converge, a CFD solver.

Once the geometry is defined, the physical processes have been correctly modeled, and the boundary conditions have been set, the solver will be used to run simulations on CHT (Conjugate Heat Transfer). Such simulations allow to achieve the heat flux map that burdens on the piston crown in a certain condition, that consequently allows to know the thermo-structural stress state of the piston.

This is still under development.

Example of the temperature distribution inside the combustion chamber during the combustion of a iso-octane and n-heptane mixture. The CFD simulation was performed using the geometry of a piston produced by Asso Werke.



PLAN FOR THE NEXT YEARS

During the second year, the candidate will finish the first part of the traineeship period at Asso Werke. Also, during the second year, the candidate will spend another period abroad at the University of Wisconsin-Madison to take a course on Converge and to further develop his skills to model with CFD.

During the third year, the candidate will perform another traineeship period at Asso Werke. In addition to that, the Candidate will soon publish a peper about the model with Prof. Frigo and Prof. Ghandhi.

MAIN REFERENCES

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[3] Shahlari, Arsham J. (2016), "An investigation of the knock measurements", Ph.D. thesis, Mechanical Engineering, University of Wisconsin-Madison.