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HD gas engine

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Motivation

Currently produced turbocharged gas engines powered by stoichiometric mixture, equipped with intercooler and Three Way Catalyst easily meet the Euro VI. Compared to the currently produced diesel engines, which to fulfill EURO VI norms require extended after treatment system - EGR, DPF, SCR - AdBlue) are very simple constructions. Unfortunately, their efficiency is still lower than diesel engines. There is a need to check what are the possibilities to improve the current state and thereby determine the solutions that could be applied in the next generation of HD gas engines.

Strategy

Theoretical thermal efficiency of the internal combustion engine comprising of:

- 1-2 isentropic compression,
- 2-3 isochoric heat supply,
- 3-4 isentropic expansion,
- 4-1 isochoric heat dissipation,

is expressed by the formula:

$$\eta_{Otto} = 1 - \varepsilon^{1-\kappa}$$

For historical reasons this cycle is called an Otto cycle.

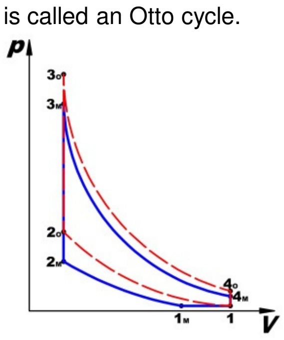

Fig. 1: Theoretical Otto and Miller cycles presented in PV diagram

$\varepsilon(V_1/V_2)$ is the engines compression ratio. The upper limit of the parameter results from the risk of self-ignition of the mixture in the cylinder. In contrast to diesel engines, here it is the undesirable phenomenon and it is called knocking.

One way to increase efficiency and avoid the risk of knocking is the use of so called Miller cycle. The solution patented by Ralph Miller in 1957 is the most widely used in the power generation gas engines (e.g. Wärtsilä, GE Jenbacher, Kawasaki).

The main characteristic of Miller cycle is shorter compression stroke $(1_M \rightarrow 2_M)$ – but geometrical stroke of the piston remains the same as in Otto cycle. Larger expansion ratio (V_{4M}/V_{3M}) is larger than compression ratio (V_{1M}/V_{2M}). It has posotive impact on overall efficiency of the engine. The higher is relation $(V_{4M}/V_{3M})/(V_{1M}/V_{2M})$, the higher is impact on efficiency improving.

Technically, it is possible that by shortening the opening duration of the intake valves. Simultaneously the effective cross-sectional area of the intake valves is reduced. In order to obtain the same amount of mixture like in the base engine boost pressure has to be increased.

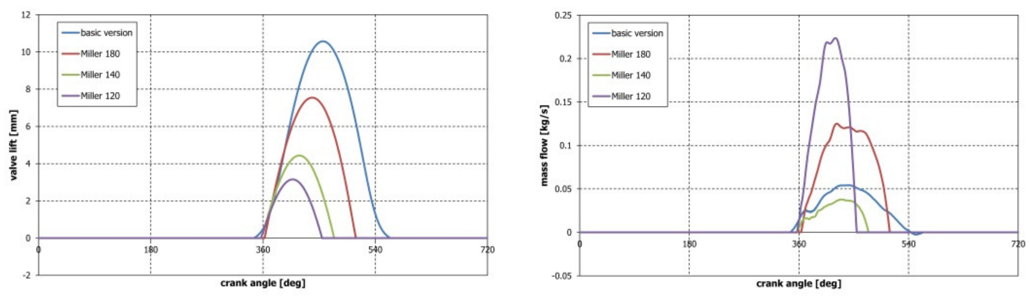

Fig. 2: Valve lift and valve mass flow for different versions of Miller cycle cams and engine basis version [900 rpm and the same torque]

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1d model → test bench

In order to verify possibilities of further emission reductions (e.g. NO_X) model also assumes the use of other engineering solutions. Below is a scheme of the engine with some of applicable solutions.

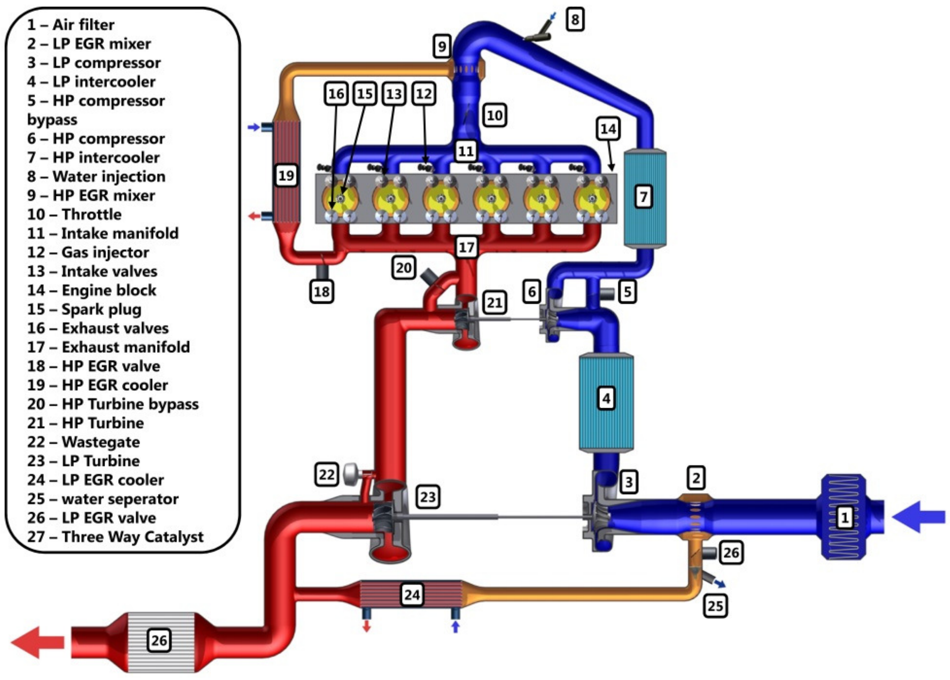

Fig. 3: Model of the HD gas engine with all possible changes

This model is used to check which of the solutions should implemented in a real engine installed on the test bench. This will allow for earlier check the potential of individual solutions before installation.

Other solutions to be considered in creating of a new generation HD gas engine include:
- water injection,
- high and low pressure Exhaust Gas Recirculation (EGR) loops,
- double stage turbocharging (serial or sequential).

First results

First results have shown the potential application of Miller cycle. Increased efficiency is clearly visible throughout the rev range. The consistent application of the Miller cycle is nearly 50% than twice higher boost pressure. From a technical point of view, the only possibility of reaching such high pressures is to use a two-stage charging with stage intercoolers.

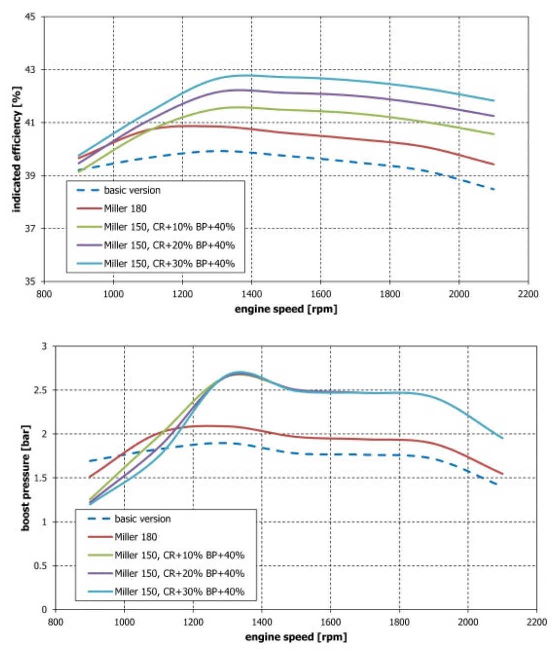

Fig. 4: Indicated efficiency and boost pressure for different versions of Miller cycle and basis version of the engine [CR – compression ratio, BP – boost pressure]

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