HCCI engine exercise

The HCCI (homogeneous charge compression ignition) engine has been subject of research for many years but as a pure engine concept it has mainly been of academic interest. However, the recent years, HCCI “like” combustion has been used in commercial vehicles too.

In light to medium duty diesel engines it has become common practice to use a pre-injection, which is a small spray pulse injected early relative to the main pulse. With pre-injection, it has become possible to reduce the characteristic diesel noise. Substituting the intense premixed combustion phase from the main injection with a less intense HCCI like pilot combustion, enables a smoother transition to the mixing controlled combustion regime.

In direct injected gasoline (GDI) engines it has become possible to increase the compression ratio by injecting later, just prior to the spark ignition. This actually causes a controlled and non-destructive amount of knocking to occur. It is a kind of HCCI combustion occurring in parts of the chamber, which is also recognized by the more knocking sound some GDI engines have.

In above cases, the timing of heat release is partly controlled by injection timing and thus the level of homogeneity. Therefore it is more correct to call it PPCI (Partially Premixed Compression Ignition) rather than HCCI. In both cases it is of high importance to understand and control the engine acoustics.

The HCCI principle in its more pure form is at its infancy of commercialization for part load conditions of SI engines. It reduces fuel consumption with about 15 %, but the technology is still expensive. One of the critical parts is the cylinder pressure sensor that is needed to control the combustion timing. These sensors are expensive and not very durable, thus not suited for commercial engines.

In this year’s exercise, we will examine the transition from HCCI to PCCI with our direct injected HCCI test engine. This year we will use n-heptane as test fuel. We will investigate how performance is influenced by the transition from HCCI to PCCI and how this transition is effected by injection timing. We will also investigate the engine acoustics of the current setup.

The HCCI test engine is a two cylinder BUKH diesel engine that has been modified to run in HCCI mode with one of the cylinders and CI mode on diesel with the other cylinder. This facilitates experiments with the HCCI cylinder as the diesel cylinder keeps the engine running even though the HCCI engine parameters are outside ignition range.

Thomas will help you through the exercise. Your reports are supposed to contain a short description of the experimental setup, so keep eyes and ears open during the exercise.

Engine parameters will be varied according to the test matrices below.

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Date	Time	Group	λ	Speed [rpm]
11-03-2025	13-15	2	6	900
11-03-2025	15-17	5	4	900
18-03-2025	13-15	1	6	1200
18-03-2025	15-17	4	4	1200
25-03-2025	13-15	3	6	1700
25-03-2025	15-17	6	4	1700

Each group will carry out test series as described below:

Test series	Injection timing [CAD BTDC]	Air/fuel equivalence ratio [-]	Intake pressure [bar]
1	No injection (motoring)	No injection	1.2
2	From 360 to -20 Jeppe knows the increments	As table	1.2
3	No injection (motoring)	No injection	1.2
4	80 CAD	Reduce λ in small steps until knocking	1.2

The measurements from all groups will be shared on Inside to enable comparison of data obtained with different engine speeds.

The assignment

This assignment report should be very short and get to the point fast. This means that you skip abstract, introduction, and conclusion. It should only contain a very brief description of the experimental setup and results in terms of plots showing the effect of parameter variations. The only (but important) writing should be discussions of the trends you see in the plots. You should also attach your Matlab code in the appendix.

An article/commercial by Mazda http://www.mazda.com/en/innovation/technology/skyactiv/skyactiv-g/ illustrates the importance of understanding auto ignition, engine knock phenomena and the importance of residual gas. In our HCCI experiments the influence by residual gas is minimized by running experiments at very lean conditions. You can also find information about the latest development Skyactive-X on the web, for example https://insidemazda.mazdausa.com/the-mazda-way/technology/five-things-need-know-worlds-first-compression-ignition-engine/

Specs:

Engine: L = 0.160 [m], S = 0.085 [m], B = 0.085 [m], R = S/2 and CR = 18.5

n-heptane: Hu = 44500 [kJ/kg] and AF ratio = 14.7 [kg/kg]

Pickup: gain = 20 bar/V and resolution = 0.1 CAD

Task 1: Investigate the effect on combustion timing during transition from HCCI to PCCI combustion mode

Create six colored surface plots of HRR with CAD as x-axis and injection timing as y-axis, one plot for each lambda value and engine speed. The surface plots are good to play around with when you try to understand the combustion process, but usually it is best presented in a report when it is shown from the top as a 2D colored map (see slide 76 in "IC engine principles" from the lectures).

Help: Pressure treatment is performed the same way as in the SI exercise but with few changes:

- The resolution of the data is 0.1 CAD
- It is a reasonable approximation to use $\gamma = 1.35$ for the heat release analysis.
- To minimize the influence of blow-by and heat loss in the test engine it is an advantage to use a **relative HRR** to create the plots. The relative HRR is found by subtracting the motored HRR from the fired HRR.
- Use the uploaded file fftBPfilter.m from programming exercise D to reduce electric noise and knocking in the pressure curves. Use the band pass filter as a low pass filter with cutting frequency set in the range of 1000 to 4000 Hz. It becomes a low pass filter if you specify a pass to go from 0 to the cutting frequency. It is usually good to use a large transition band width (also in the range of 1000 to 4000 Hz) to get a smooth cut.
- For this engine it is a reasonable approximation to assume $T = T_{intake}$ and $p = p_{intake}$ at -180 CAD for the adjustment of the cylinder pressure and calculation of the in-cylinder bulk gas temperature. Use 1 CAD shift of TDC relative to the location of maximum pressure in the motoring.
- An example script on how to make surface is uploaded as Surf_example.m.

Task 2: Investigate the effect on combustion efficiency during transition from HCCI to PCCI combustion mode

Plot IMEP and indicated efficiency as function of injection timing. To minimize the effect of blow-by and heat loss you should use IMEP based on torque measurements (see the help). All three engine speeds should be shown in the same plot for each λ with well-chosen line styles and legends.

Discuss what happens with the combustion process when the injection timing moves closer to TDC. What happens when engine speed and lambda is changed. Consider effects of homogeneity, temperature and crevice volumes. Note that combustion may occur in two separated steps, cool reactions (flame) where the fuel cracks into CO and H_2, and a hot flame where the CO and H_2 burns. Use plots from both task 1 and task 2 to support your understanding and explanations.

Help:

- IMEP should be determined by torque measurements in the current setup. This can be done by subtracting the torque of the diesel cylinder during motoring from the torque you measured when both cylinders where firing. Then you will get the indicated torque from the HCCI cylinder if the fuel supply to the diesel engine was unchanged.

Task 3: Investigate the engine acoustics

The engine piston used in the experiments have a bowl similar to traditional diesel engines (see slide 70 in "IC engine principles" lower left image), thus the geometry is rather complex for acoustic modeling. However, with a spectral analysis of the pressure oscillations it is possible to show quite good agreement with simple approximate models (as in programming exercise D). Use the knock tests made at each engine speeds. Carry out a spectral analysis of the knock for an interval of 10 CAD starting slightly after the heat release has peaked (typically around 50% heat release). Plot the spectrum and compare the measured frequencies with theoretically calculated resonance frequencies. Both use the bore of 85 mm and the bowl diameter of 41 mm to see if you can find the resonance frequencies.

Help:

- Use a single, representative pressure curve when you make spectral analysis of the knocking.
- Subtract a low pass filtered pressure curve from the unfiltered curve to get a knock curve. Pick the 10 CAD interval to be analyzed from the knock curve.
- Use the uploaded Matlab function `FFTanalyze.m` from programming exercise D to determine the spectrum of the knock.
- The theory for calculating resonance frequencies based on cylinder bore and an estimated gas temperatures may be found in the article: http://www.lth.se/fileadmin/lth/student/Maskinteknik/Filer/Examensarbete/Lundin_Vressner.pdf but use a $\gamma = 1.29$ for calculating the speed of sound in n-heptane combustion products.