HCCI Combustion Phasing Transient Control by Hydrogen: Investigation Using a Fast Detailed-Chemistry Full-Cycle Model

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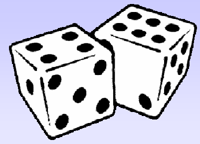


1. Introduction

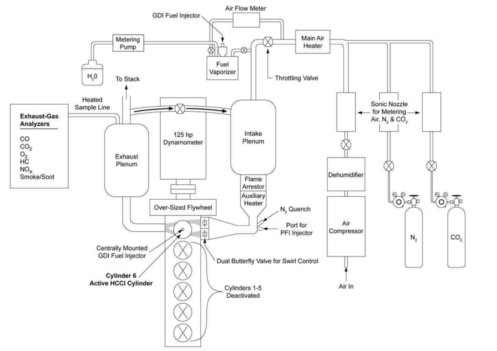
- The homogenous-charge compression-ignition (HCCI) concept offers a promising alternative to current modes of combustion in internal combustion engines.
- In HCCI, the start and rate of combustion are solely dependent on the thermo-chemical conditions inside the combustion chamber. The lack of external control results in operational difficulties at low and high load operation.
- A dual-fuel strategy to control combustion phasing during HCCI transients is investigated using a detailed-chemistry full-cycle modelling approach.
- A detailed-chemistry zero-dimensional stochastic reactor model is coupled with a one-dimensional GT-Power engine model to account for the full engine cycle. GT-Power simulates the open-volume portion of the cycle and passes the closed-volume initial conditions to the SRM at the IVC point.
- The model simulates steady-state and transient operation of a single-cylinder HCCI engine fuelled with primary reference fuels (mixtures of iso-octane and normal-heptane). The combustion phasing is controlled by varying the octane number or the hydrogen ratio in the base fuel.

2. Modelled Engine

Engine specifications:

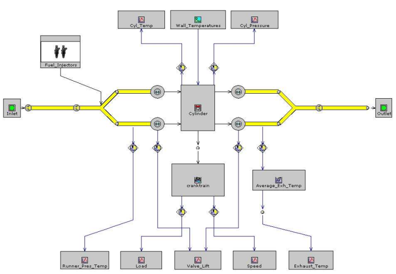
Cylinder displacement (litres)	0.981
Bore × Stroke (mm)	102 × 120
Connecting rod length (mm)	192
Compression ratio	13.81
Number of valves	4
IVO (CA)*	357
IVC (CA)*	-155
EVO (CA)*	120
EVC (CA)*	-352

* CA (crank angle) measured with respect to firing TDC

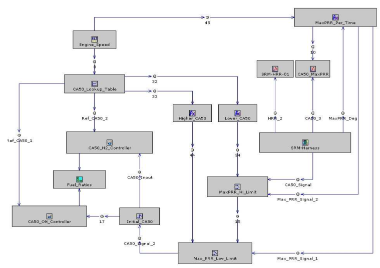


A schematic of the modelled engine. A Cummins six-cylinder medium-duty diesel engine is converted to a single-cylinder HCCI engine. The five remaining cylinders are deactivated but kept for dynamic balancing. The engine is equipped with both port and direct injection capabilities [3].

3. GT-Power Engine Model and Controller

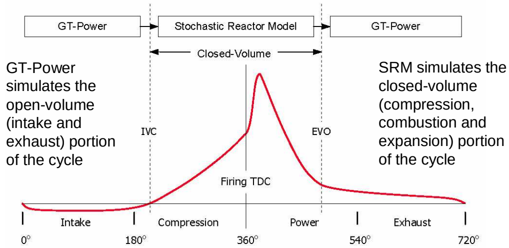


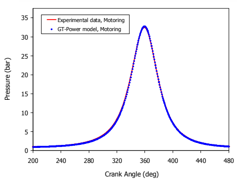
A GT-Power map of the modelled engine. The model accounts only for the active cylinder and part of the intake and exhaust systems, and only considers the pre-mixed fuelling option.



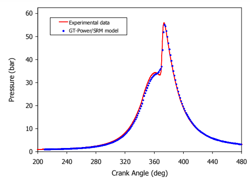
A GT-Power map of the PID combustion phasing controller. The phasing (CA50) is either controlled by changing octane number or hydrogen ratio. Pressure rise rate (PRR) signal is used to limit the phasing at the knocking and misfire boundaries.

4. Coupling GT-Power with SRM

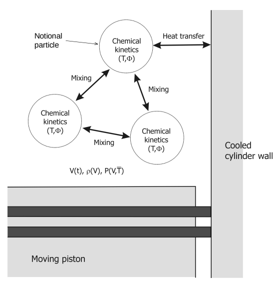




Validation at motored operation and an engine speed of 1200 rpm

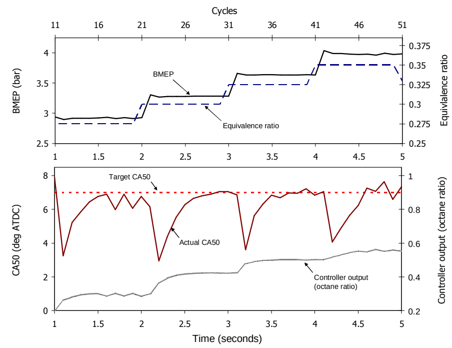


Validation at fired operation, engine speed of 1200 rpm and equivalence ratio (Φ) of 0.44

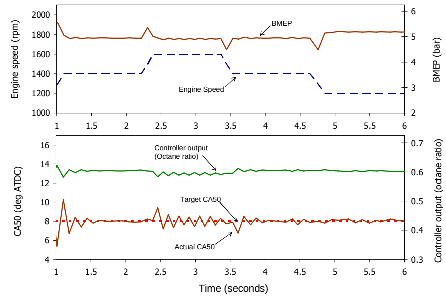


- The stochastic reactor model (SRM) uses the "particle" method to account for time-evolution of physical and chemical quantities in the cylinder.
- The method uses an ensemble of notional particles which carry no spatial information.
- Volume, density, and pressure are treated as global variables, while temperature and composition evolve independently in each particle according to a probability density function (PDF).
- A detailed PRF chemical mechanism is used. Mixing takes place based on EMST method, and convective heat transfer is accounted for using Woschni's heat transfer coefficient.

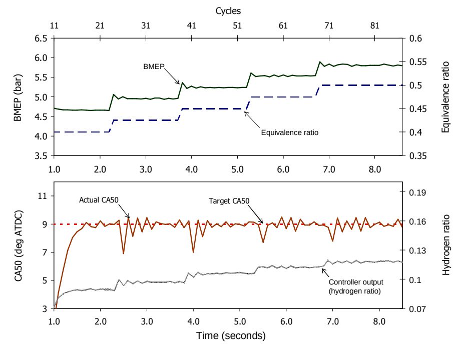
5. Results



Response of the octane number controller to step changes in load at 1200 rpm. CA50 settles at ±0.5° of target value within about 7 cycles. Use of a fixed set of gains causes a relative instability in the response at the two ends of the test.



Response of the octane number controller to variations in speed at Φ=0.44. CA50 is not largely sensitive to variation in speed as the shorter time available to combustion at higher speed is compensated by higher temperature at IVC and vice versa.



Response of the hydrogen controller to step changes in load at 1200 rpm and with base fuel octane number of 44. CA50 settles at ±0.5° of target value within less than 7 cycles.

6. Conclusions

1. The coupling of GT-Power, SRM and closed-loop control provided an effective tool to simulate HCCI transients and investigate potential strategies to control HCCI combustion.
2. The results suggest that both octane number and hydrogen addition can be effectively used to control combustion phasing in HCCI engines. Further investigations are needed, however, to fully understand their limits and effects on the operating window.

7. References

http://como.cheng.cam.ac.uk

1. S. Mosbach, M. Kraft, A. Bhave, F. Mauss, J. Hunter Mack, and Robert W. Dibble. Simulating a homogenous charge compression ignition engine fuelled with a DEE/EtOH blend. SAE Paper No. 2006-01-1362, 2006.
2. S. Mosbach, A. Aldawood and M. Kraft. Real-time evaluation of a detailed chemistry HCCI engine model using a tabulation technique. *Combustion Science and Technology*, vol. 180, no. 7, pp. 1263-1277, 2008.
3. M. Sjöberg and J. Dec. An investigation of the relationship between measured intake temperature, BDC temperature, and combustion phasing for premixed and DI HCCI engines. SAE paper No. 2004-01-1900, 2004.

8. Acknowledgement

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