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Amin Modabberian*, Xiaguo Storm, Aneesh Vasudev, Kai Zenger, and Maciej Mikulski

Towards Low Emission Combustion Control in Marine Applications

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***Corresponding Author: Amin Modabberian:** Aalto University, Department of Electrical Engineering and Automation, E-mail: amin.modabberian@aalto.fi
Xiaguo Storm: University of Vaasa, School of Technology and Innovations, Energy Technology, E-mail: xiaguo.storm@uwasa.fi
Aneesh Vasudev: University of Vaasa, School of Technology and Innovations, Energy Technology, E-mail: aneesh.vasudev@uwasa.fi
Kai Zenger: Aalto University, Department of Electrical Engineering and Automation, E-mail: kai.zenger@aalto.fi
Maciej Mikulski: University of Vaasa, School of Technology and Innovations, Energy Technology, E-mail: maciej.mikulski@uwasa.fi

1 Extended abstract

Energy - its sufficiency and production with low emission technologies - are the current and upcoming global key challenges. In the automotive and off-road sector the transition into fully electric low-emission technology is on-going. However, e.g. in marine applications (passenger and cargo ships) the energy density of electric engines is not enough to drive the ships, and there is no change foreseen for it in the near future. The traditional diesel engines function well, but they use fossil fuel and produce an intolerable amount of emissions (soot, particulate matter, nitrogen dioxide (NO_2) and carbon dioxide (CO_2)). Carbon dioxide is a greenhouse gas, and its reduction in the atmosphere is currently the main environmental challenge.

The solution to the aforementioned problem is the development of engines, which use new environmentally friendly combustion technologies. These are different from the traditional combustion engines in that they operate in much lower temperatures, leading to a radical reduction of emissions. Some of these new combustion technologies are: Partially premixed combustion (PPC), homogeneous charge compression ignition (HCCI) and reactivity controlled compression ignition (RCCI). These processes are quite promising. However, their modeling and control is a complex task compared to the traditional engines. This is due to the fact that the new combustion processes use dual-fuel injections, which leads to complex physico-chemical reactions taking place inside the cylinders.

RCCI technology has been an area of interest among research communities for the next generation of combustion engines [1] due to its ability of reaching ultra low levels of soot and NO_x, and having a high thermal efficiency [2, 3]. However, certain issues challenge the adaptation of RCCI in terms of model-based control design (MBCD). These include complex thermo-kinetic reactions, high pressure rise rate at high load operating conditions, low combustion efficiency at low load operating conditions, increasing system complexity and highly nonlinear system dynamics and extensive calibration space. [4, 5]

This work presents a physics-based time-varying RCCI combustion model capable of real-time simulations and can predict the start of combustion (SOC), heat-release, and cylinder pressure of an RCCI marine engine. The model is further extended and improved with a semi-predictive combustion phasing model and a physics-based emission model. The modelling in this work is part of the simplification of a more accurate physics-based model called the University of Vaasa Advanced Thermo-kinetic Multizone Model (UVATZ), developed by Vasudev et al. [6]. Eventually, this model is controlled with model-predictive control (MPC) cycle-wise.

The combustion model simulates the RCCI process based on the values of fuel blend ratio (BR), excess air ratio (λ), temperature and pressure at IVC, and equivalence ratios of low and high reactivity fuels (LRF, HRF). Subsequently, it obtains essential combustion parameters, such as cylinder pressure and temperature, maximum pressure rise rate, indicated mean effective pressure (IMEP) and combustion phasing. Additionally, it calculates the emission of NO_x, CO_x and PM based on the values of aforementioned combustion parameters.

The MPC is chosen due to its ability of solving the optimization problem utilizing a moving horizon window [7] corresponding to a engine cycle in this application. In this work, MPC is used to control the aforementioned parameters to maintain cylinder pressure and temperature, and IMEP at levels optimal over a cycle to achieve low-temperature combustion characteristics, and eventually low emission levels.

The developed system will later be tested on a 4-cylinder test engine at VEBIC laboratory in Vaasa, which operates on RCCI and conventional diesel combustion modes.

References

[1] Mikulski M, Ramesh S, Bekdemir C. Reactivity Controlled Compression Ignition for clean and efficient ship propulsion. *Energy*. 2019;182:1173–1192.

[2] Benajes J, Pastor JV, García A, Monsalve-Serrano J. The potential of RCCI concept to meet EURO VI NOx limitation and ultra-low soot emissions in a heavy-duty engine over the whole engine map. *Fuel*. 2015;159:952–961.

[3] Splitter D, Hanson R, Kokjohn S, Reitz RD. Reactivity controlled compression ignition (RCCI) heavy-duty engine operation at mid-and high-loads with conventional and alternative fuels. In: *SAE World Congress & Exhibition*. SAE International. 2011; .

[4] Vasudev A, Cafari A, Axelsson M, Mikulski M, Hyvonen J. Towards Next Generation Control-Oriented Thermo-Kinetic Model for Reactivity Controlled Compression Ignition Marine Engines. In: *SAE Powertrains, Fuels & Lubricants Conference & Exhibition*. SAE International. 2022; .

[5] Reitz RD, Duraisamy G. Review of high efficiency and clean reactivity controlled compression ignition (RCCI) combustion in internal combustion engines. *Progress in Energy and Combustion Science*. 2015;46:12–71.

[6] Vasudev A, Mikulski M, Balakrishnan PR, Storm X, Hunicz J. Thermo-kinetic multi-zone modelling of low temperature combustion engines. *Progress in Energy and Combustion Science*. 2022;91:100998.

[7] Wang L. *Model predictive control system design and implementation using MATLAB®*. Springer Science & Business Media. 2009.