Robustness analysis of the next generation of EGR controllers in marine two-stroke diesel engines

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Synopsis

Exhaust Gas Recirculation (EGR) has recently been introduced in large marine two-stroke diesel engines to reduce NO_x emissions. During accelerations, controlling the amount of EGR flow while still keeping good acceleration performance can be quite challenging. The main difficulties to overcome are the delay in the scavenge receiver oxygen measurement and the upper limit in the amount of fuel that can be burned with EGR diluted air without producing black smoke. Previous oxygen feedback controllers struggled during accelerations, but a new approach to EGR control based on adaptive feedforward (AFF) has been tested successfully. Nevertheless, further analysis and tests are required before deploying the new controller to more EGR ships. A simulation platform is a great asset to test the controllers before expensive and time-limited real-world experiments have to be conducted on board of ships. With this purpose, a new EGR flow controller is introduced to track the AFF controller EGR flow setpoint in a complete ship simulation model. This new EGR controller complements the previous AFF controller and determines the control signals of the engine EGR blowers. Several acceleration scenarios are simulated, and they identify the low load area as the most challenging concerning EGR control performance due to the slower air path engine dynamics. Controller robustness in this low load area against errors in the flow estimates used by the controller is analysed. Pressure sensor bias in the EGR flow estimator is identified as the most critical factor, which could lead to black smoke formation. This issue could be prevented with better sensor calibration or by using a differential pressure sensor in the estimator instead of two absolute pressure sensors. Errors in the parameters of the flow estimators do not affect the performance as much. This is a useful result because, for a newly built engine, the right parameters of the flow estimators might be difficult to obtain.

Keywords: Split-range control; Exhaust Gas Recirculation; Marine pollution; Engine control

1 Introduction

Developing a clean and efficient transportation sector is one of the most important goals for any society. Road transport started to define more strict emission limits of CO_2 and other pollutants several decades ago. While marine freight began to be regulated later, but in the past years, significant steps have been taken to reduce its environmental impact. The latest is the stricter Tier III emission limit, which enforces a substantial NO_x reduction for vessels built after January 2016 in certain coastal NO_x Emission Control Areas (NECAs), see International Maritime Organization (2013).

One method to reduce the thermal NO_x formed during the combustion is Exhaust Gas Recirculation (EGR). By recirculating burned gases back into the cylinders, the heat capacity of the air is increased which results in lower cylinder peak temperatures and thus less NO_x formation. EGR has been widely investigated in the automotive sector, e.g., Nieuwstadt et al. (2000); Ammann et al. (2003) among many more, but it has only recently been introduced in large two-stroke diesel engines.

Maintaining a high EGR rate when the vessel is manoeurving in a NECA without smoke formation is a challenging task for the current EGR controllers. The reduced oxygen availability during EGR operation limits the amount of fuel that can be burned without visible black smoke formation. This issue together with the industry trend to downsize the engines for fuel economy can reduce the vessel manoeuvrability. Moreover, the oxygen measurement contains inherent delays due to a required gas extraction process, which caused the original PI feedback to perform poorly in these situations. Hence, better EGR controllers that more appropriately handle these acceleration scenarios are crucial for the emission reduction and introduction of EGR on marine diesel engines.

The controller developed in Nielsen et al. (2017b), that uses an adaptive feedforward (AFF) algorithm, showed to have a great potential to improve the acceleration performance during vessel engine testing. However, before the proposed solution can be adopted widely to more EGR engines, further testing has to be carried out to verify the robustness of the complete installation. Since engine testing is limited by the amount of available EGR engines built and also due to high costs of vessel testing, a full vessel and EGR engine model was developed in Llamas

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Authors' Biographies

Xavier Llamas is currently a PhD student at Linköping University. His principal research topic is about modelling and control of EGR on marine two-stroke diesel engines. Moreover, he is also interested in modelling and control of turbocharged combustion engines for road vehicle applications.

Prof. Lars Eriksson is a professor of vehicular systems at the Department of Electrical Engineering, Linköping University. His research interests are modelling, simulation and control of vehicle propulsion systems where he has a special interest in issues related to internal combustion engines and vehicle powertrains for clean and efficient transportation.