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Control-oriented modeling of two-stroke diesel engines with EGR for marine applications

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Abstract

Large marine two-stroke diesel engines are widely used as propulsion systems for shipping worldwide and are facing stricter NO_x emission limits. Exhaust gas recirculation (EGR) is introduced to these engines to reduce the produced combustion NO_x to the allowed levels. Since the current number of engines built with EGR is low and engine testing is very expensive, a powerful alternative for developing EGR controllers for such engines is to use control-oriented simulation models. Unfortunately, the same reasons that motivate the use of simulation models also hinder the capacity to obtain sufficient measurement data at different operating points for developing the models. A Mean Value Engine Model (MVEM) of a large two-stroke diesel with EGR that can be simulated faster than real time is presented and validated. An analytic model for the cylinder pressure that captures the effects of changes in the fuel control inputs is also developed and validated with cylinder pressure measurements. A parameterization procedure that deals with the low number of measurement data available is proposed. After the parameterization, the model is shown to capture the stationary operation of the real engine well. The transient prediction capability of the model is also considered satisfactory which is important if the model is to be used for EGR controller development during transients. Furthermore, the experience gathered while developing the model about essential signals to be measured is summarized, which can be very helpful for future applications of the model. Finally, models for the ship propeller and resistance are also investigated, showing good agreement with the measured ship sailing signals during maneuvers. These models give a complete vessel model and make it possible to simulate various maneuvering scenarios, giving different loading profiles that can be used to investigate the performance of EGR and other controllers during transients.

Keywords

Mean Value Engine Model, Dynamic Simulation, Parameterization, Exhaust Gas Recirculation, Ship Propulsion

1 Introduction

Over the last year, maritime transport growth slowed down. However, shipping is still growing, and for the first time the estimated world seaborne trade volume surpassed 10 billion tons.[1] The required technical development to achieve an overall clean and efficient transportation in our society has to involve the marine sector as well. The regulations that have driven the automotive industry started several decades ago, while the regulations affecting marine diesels began at the beginning of the last decade. Hence, the process of reducing the environmental impact of the shipping industry is ongoing. The International Maritime Organization has developed the stricter Tier III emission limits[2] on NO_x, for new vessels built after January 2016.

Low-speed two-stroke diesel engines usually propel the largest vessels, e.g., tankers, bulk carriers, and container ships. These low-speed engines have high fuel efficiency, however, they are also responsible for large amounts of pollutant emissions, like NO_x and SO_x. The large reduction in NO_x emissions enforced by the Tier III compared to the previous Tier II regulations cannot be fulfilled by only improving the combustion of these engines. Thus, new technologies are being developed in order to attain the emission reductions while still keeping a good specific fuel oil consumption (SFOC), which is a good indication of CO_2 emissions. The two most common technical solutions are Selective Catalytic Reduction (SCR) and Exhaust Gas Recirculation, (EGR). SCR is an after-treatment technology

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