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Engine Efficiency Optimization under Consideration of NO_X- and Knock-Limits for Medium Speed Dual Fuel Engines in Cylinder Cut-Out Operation

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Abstract

As a consequence of the global warming, more strict maritime emission regulations are globally in force or will become applicable in the near future (e.g. NO_X and SO_X emission control areas). The tough competition puts economic pressure on the maritime transport industry. Therefore, the demand for efficient and mostly environmental neutral propulsion systems that meet the environmental legislations and minimize the cargo costs are immense. Medium speed dual fuel engines are in accordance with the strict maritime emissions legislation IMO Tier III. They do not require any exhaust gas aftertreatment, are economically competitive, and allow fuel flexibility. These engines deliver the highest efficiency in high load operation. A valuable approach to improve the efficiency and reduce the environmental impact in low and part load is represented by the electronic cylinder cut-out. Thereby, the natural gas admission is deactivated and the valves are kept activated. It is investigated with the help of a developed 1D GT-Power simulation model of a medium speed dual fuel engine. The predictive model is adjusted to a measured engine map (test bench data) by an optimization workflow that is set up in Optimus. The cylinder cut-out is analyzed with special emphasis on efficiency, NO emissions, and methane slip. Different static cut-out scenarios are simulated and assessed for constant relative air/fuel ratios and varying load. An optimization workflow is developed and set up in Optimus. The selected evolutionary algorithm changes the number of cut-out cylinders and the relative air fuel ratio to optimize the engine efficiency under consideration of IMO Tier III NO_X emission regulations and the knock onset. The optimization is conducted for discrete engine operation points in a load range from 10% to 50%. The optimization predicts a significant increase of the brake efficiency and reduced methane slip at low and part load operation. This depends on an increased turbocharger efficiency, reduced pumping work, richer combustion, and higher indicated mean effective pressures of the fired cylinders that leads to an improved combustion (shifted from diffusion to premix) and engine efficiency without exceeding the NO_X - and knock-limits.

Introduction

In maritime business the internal combustion engine will maintain its important role in a long term [1]. Efficiency, reliability, and energy density, combined with the global availability of liquid fuel, are some of their major advantages. The economic aspects are of great importance but next to them the maritime industry has to consider and fulfil the strict IMO Tier III emission regulations of airborne oxides of sulphur (SO_X) and oxides of nitrogen (NO_X). A growing number of SO_X Emission Control Areas (SECA) has been in force since 2006. Furthermore, the fuel's sulphur content is limited to 0.1% in the SECA and will be worldwide limited to 0.5% from 2020 [2]. NO_X Emission Control Areas (NECA) are already established in North America and will follow in the Baltic and North Sea after January 1, 2021 [3, 4]. Globally, further ECA are currently under discussion, e.g., Mexico, the Mediterranean Sea, and the Black Sea, and some of them will probably become in force in the near future [5, 6].

The tough competition puts economic pressure on the maritime transport industry. Therefore, the demand for efficient and mostly environmentally neutral propulsion systems that meet the emission legislations and minimize the cargo costs is immense. A good match of these entire requirements is represented by the dual fuel engine. Fuel flexibility, combined with high efficiency and the possibility of fulfilling all environmental demands without exhaust gas aftertreatment, makes this kind of engine highly interesting for the maritime industry.

Medium speed dual fuel engines are designed to deliver the highest efficiency and the most economic performance in high load operation [7]. However, in maritime transportation of passengers and goods, economic and punctual operation is the most important. To achieve planned arrival times and to avoid anchoring, low and part load operation can be necessary. Furthermore, low and part load operation is also applied for maneuvering, nautical station keeping, dynamic positioning, as well as auxiliary energy supply.

Medium speed engines typically operate with rotational speed in the range from 300 rpm to 1000 rpm and do not have throttling valves [8]. On the one hand, this has the positive effect of reduced pumping losses, yet, on the other hand, the desirable restriction of the air flow in low load is not possible. This leads to a very lean fuel air mixture in low load [9]. Due to the increased energy demand to ignite the lean mixture, the share of pilot fuel has to be elevated and a shift from mostly premixed to distinct diffusion combustion is a consequence. This results in high combustion temperatures and enhanced formation of NO_X [10]. If the mixture is too lean, ignition is not possible and misfiring emerges [9].

A valuable approach to improve the efficiency, reduce the environmental impact in low and part load, and prevent misfiring is represented by the cylinder cut-out. The cut-out of one or more