A Model of a Marine Two-Stroke Diesel Engine with EGR for Low Load Simulation

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***Abstract*—A mean value engine model of a two-stroke marine diesel engine with EGR that is capable of simulating during low load operation is developed. In order to be able to perform low load simulations, a compressor model capable of low speed extrapolation is also investigated and parameterized for two different compressors. Moreover, a parameterization procedure to get good parameters for both stationary and dynamic simulations is described and applied. The model is validated for two engine layouts of the same test engine but with different turbocharger units. The simulation results show a good agreement with the different measured signals, including the oxygen content in the scavenging manifold.**

I. Introduction

The marine shipping industry is facing increased demands in the reduction of harmful exhaust gas emissions. Stricter emission limits of Sulphur Oxides (SOx) and Nitrogen Oxides (NOx) are imposed in certain Emission Control Areas (ECAs). The emission values to fulfill in these ECAs are set by the IMO Tier III limits [1] that came into play in January 2016. One of the available technical solutions to achieve the targeted reduction in NOx emissions is Exhaust Gas Recirculation (EGR). An EGR system recirculates a fraction of the exhaust gas into the scavenging manifold, providing burned gases in the combustion chamber that directly decreases the production of NOx during the combustion.

EGR technologies for two-stroke engines are still at the initial phases of its development. In addition, there are not many available vessels with an EGR system installed and thus performing tests is often difficult. Furthermore, testing any new system in marine two-stroke engines is also very costly mainly due to the fuel cost associated with the sizes of such engines. Hence, in order to improve the performance of the EGR control systems, a fast and accurate simulation model is a very valuable tool.

Mean Value Engine Models (MVEMs), are a very common approach for control oriented modeling of internal combustion engines. In particular, EGR systems have been also modeled using this approach. Many interesting research articles about EGR modeling in automotive applications can be found in the literature, some examples are, [2] and [3]. On the other hand, marine two-stroke engines have not been widely studied. Nevertheless, some research papers focused on MVEMs for two-stroke engines are [4], [5] and [6]. In addition, in [7] the modeling of the low load operation of a two-stroke engine without EGR is studied.

The work presented here is an extension of the model proposed in [8], which enables the model to simulate low engine loads. The low load operation is very relevant for the EGR control since the Tier III emission limits have to be fulfilled near certain coasts, e.g. harbors, where the vessel is normally operating at low loads. The main new component that needs to be introduced for this low load simulation is the auxiliary electrical blower. Its mission is to ensure that there is enough scavenging pressure at low loads when the turbocharger is not capable to provide it. Moreover, the turbocharger model will be required to simulate at low speeds and pressure ratios. This area is normally not measured in the provided performance maps, so a model that can extrapolate to this area is also required.

The developed model is, as in [8], based on the 4T50ME-X test engine from MAN Diesel & Turbo. The 4T50ME-X is a two-stroke uniflow diesel engine, turbocharged, with variable valve timing and direct injection. Its maximum rated power is $7080\,kW$ at $123\,rpm$. Also, it is equipped with an EGR system and a Cylinder Bypass Valve (CBV).

II. Experimental data

The targeted test engine is constantly being rebuilt to test new components and new control strategies. This implies that it is difficult to find measurement data from the same engine configuration. Most of the measurement data available is from the same layout as the data used in [8]. For layout number 1 the oxygen sensors were not properly calibrated and thus cannot be used for validating the oxygen levels at the manifolds. For the model parameterization 30 different stationary points are extracted from the measurement data. another 24 stationary points are saved for the validation.

Some more data is available from another layout of the engine and will be used for validation of the oxygen level in the scavenging manifold. However, in this layout, number 2, the turbocharger was changed and some sensors where removed. Moreover, there is much less data available, and only 18 stationary points could be extracted for the parameterization and the validation of the model.