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Control-Oriented Compressor Model with Adiabatic Efficiency Extrapolation

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ABSTRACT

Downsizing and turbocharging with single or multiple stages has been one of the main solutions to decrease fuel consumption and harmful exhaust emissions, while keeping a sufficient power output. An accurate and reliable control-oriented compressor model can be very helpful during the development phase, as well as for engine calibration, control design, diagnostic purposes or observer design. A complete compressor model consisting of mass flow and efficiency models is developed and motivated. The proposed model is not only able to represent accurately the normal region measured in a compressor map but also it is capable to extrapolate to low compressor speeds. Moreover, the efficiency extrapolation is studied by analyzing the known problem with heat transfer from the hot turbine side, which introduces errors in the measurements done in standard gas stands. Since the parameterization of the model is an important and necessary step in the modeling, a tailored parameterization approach is presented based on Total Least Squares. A standard compressor map is the only data required to parameterize the model. The parameterization is tested with a database of more than 230 compressor maps showing that it can deal well with different compressor sizes and characteristics. Also, general initialization values for the model parameters are provided using the complete database parameterization results. The results show that the model accuracy is good and in general achieves relative errors below one percent. A comparison of the model accuracy for compressor maps with and without heat transfer influence is carried out, showing a similar model accuracy for both cases but better when no heat transfer is present. Furthermore, it is shown that the model is capable to predict the efficiency characteristics at low speed of two compressor maps, measured with near adiabatic conditions.

1 INTRODUCTION

The legislation pressure on the exhaust emission limits drive the automotive industry into researching more advanced technologies. Moreover, the increasing fuel prices, also push the need to develop more and more fuel efficient internal combustion engines (ICE). One of the most popular solutions to achieve these demands is downsizing and turbocharging the ICE. Many examples of boosting systems exist nowadays, e.g. from various turbocharger stages to electrically driven compressors. Introducing more and newer components into a ICE makes the complete system more complex to deal with. First, in terms of system design choices, later due to the complexity that arises from having to control the ICE as efficient as possible. In order to overcome this, having a simulation model to apply model-based control techniques can be very useful to benchmark different system architectures as well as to test different control strategies.

In model-based control, a model that is capable to capture the main dynamic characteristics of the system is required. At the same time, this model has to be computationally low demanding. Mean value engine models (MVEM) fulfill these two requirements, and have been successfully applied to many different types of combustion engines, see e.g. [1, 2, 3]. A control-oriented compressor model is required as a part of the complete MVEM. This family of compressor models has also received significant attention in the automotive research literature, see among many others [4, 5, 6, 7, 8, 9].

In the research literature, the compressor efficiency modeling has received less attention than the mass flow modeling. One reason for that could be the known problem with heat transfer from the hot turbine gases in the gas stand, which introduces errors in the compressor efficiency measurements. This issue has a greater effect at low compressor speeds, as it is pointed out in [10, 11, 12, 13, 14] among many others. The fact that normal compressor maps are only measured down to $35\% - 40\%$ of the maximum rotational speed adds even more uncertainty to what is the true value of the compressor efficiency in this area. This in turn makes the validation of the efficiency extrapolation a difficult task.

The main objective of this investigation is to continue the work carried out in [15] for centrifugal compressors used in marine propulsion. The focus here is to apply the modeling approach together with an updated estimation procedure to automotive compressors. Hence, the general applicability of the model and parameterization method to any compressor size is demonstrated. At the same time an investigation of how the heat transfer affects the compressor efficiency is done. This motivates some changes in the efficiency model compared to