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DIESEL ENGINE MODELLING

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Mathematical modelling of internal combustion engines is a far reaching subject. In the development of engine models over the years we may distinguish three main steps: thermodynamic models based on mass and energy conservation laws have been used since 1950 to help engine design or subsystems matching and to enhance engine processes understanding; Empirical models based on inputoutput relations were introduced in early 1970s for primary control investigation; Physically based nonlinear models for both engine simulation and control design. Engine modelling for control tasks involves researchers from different disciplines, i. e. engineering, control and physics. Therefore, several specific nominations may be used for the same class of model in accordance with the framework. To avoid any misunderstanding, Guzzella and Amstutz, show three categories to classify the different modelling approaches with terminology adapted to the basic principle of the model:

Thermodynamic-based models (known also as, knowledge model, or parametric model, or white box), have been derived using physical first principles and include relatively few physical parameters which are very suitable for control.

Non-thermodynamic models (black-box, or non-parametric model), that use a prior chosen structure, and reflect the input output relationship of the engine based on experimental input-output analysis.

Semi-physical approximate models (or grey-box) which is an intermediate category where the model was built with equations derived from physical laws and which parameters are measured or estimated using identification techniques.

This classification is very helpful but it may be oversimplified because a complete engine model would be a mixture of physical and experimental sub-models. The following section will focus on the first two categories as the third category is mixture of the first two.

Thermodynamic diesel engine modelling passed through a long term development as early efforts in the 1950s focused on the closed part of the engine cycle, i. e. the compression/combustion/expansion sequence. These models evolved from the ideal cycle calculations in the 1950s to simple component matching models in the 1960s and multizone and multidimensional combustion models in the 1980s and early 1990s, Chow and Wyszynski. High resolution multidimensional models, such as KIVA II 3-D introduced by Mariani and Postrioti are often used for specific problem areas in engine design, where details of fluid transport processes or those involving subtle geometry changes dominate.

Quasi-steady models are simple and have the advantage of short run times, and for this reason they are suitable for real-time simulation. On the other hand, among the disadvantages of quasi-steady models are their heavy reliance on experimental data and low accuracy. A quasi-steady model requires a large amount of data to obtain empirical relations or maps for each engine component; furthermore, it cannot be transposed to other engines. Complex phenomena such as combustion or gas flow are oversimplified and thus reduce the simulation accuracy. These models do not provide a sufficient level of detail to reflect design change or to predict parameters that influence exhaust emissions Watson.

The filling and emptying models are based on solving the mass and energy conservation equations of a thermodynamic control volume. This method represents the unsteady flow phenomena more realistically as it models the time varying properties of flow and allows for mass accumulation between the engine system components. The main motivation for using the filling and emptying method is to give general engine models with minimum empirical data requirement. Therefore, the model may be adapted to different types of engines with minimum effort. Filling and emptying model exhibit good prediction of engine performance under both steady and transient conditions and gives information on parameters known to influence pollutant emissions or noise. However, assumption of uniform state of gas covers up complex acoustic phenomena (resonance). Wave effects inside the manifold can affect engine performance, and thus, the error introduced by filling and emptying method must be considered. The filling and empting model is not suitable to control design application because of their prohibitive computing time.

The cylinder-by-cylinder model, based on the filling and emptying method firstly established by Watson was of a turbocharged diesel engine simulator which has been designed to help in the development of an electronic controller. A nonlinear dynamic simulation of a turbocharged diesel engine was presented. The detail of the model was governed by the desire to accurately predict fuel economy of new engine designs currently on the drawing board, but without any empirical input, and respond correctly to changing ambient conditions, design alterations etc. Thus the model treats cylinders and manifolds as thermodynamic control volumes, solving energy and mass conservation equations with subroutines for combustion, heat transfer, turbocharger, dynamic aspects etc. In-cylinder calculations are performed in small engine crank-angle steps so that the correct ignition crank angle is predicted as well as the subsequent fuel burning rate. This enables parameters such as the cylinder pressure and diffusion burning factor to be predicted. It is shown how the run time of a previous model has been reduced by an order of magnitude. The accuracy of the model was tested and verified by comparison between measured and predicted performance over the complete steady state operating range of the engine. Also, the engine response to acceleration and full-load application was tested.

Complex thermodynamic models are unsuitable for analytical controller design where it used to solve complex differential and algebraic equations; hence simple non-thermodynamic models were the first kind of engine models used for control purposes. Non-thermodynamic, known as black-box, models they were built with the minimum level of knowledge about the system, and no fundamental principles are involved. However, they can include a priori information about the engine such as, time delay or engine nonlinearities. These models have to reproduce the input-output behaviour of the system and their structure (transfer function or statespace representation) complies with the control requirement. The modelling procedure consists of four important steps: Experimental data recording, choosing an adequate model structure and the identification algorithm, calculation of the model parameters and validation. In the following section, the "black-box" models of diesel engine will be split into two classes: linear and nonlinear models.