Dipl. Ing. German Weisser, Dr. sc. techn.
Fellenbergstrasse 219
CH-8047 Zürich
Switzerland

Reviewer's Assessment

Ph.D. Thesis:

„Phenomenological Combustion Modeling for Optimization of Large 2-stroke Marine Engines under both Diesel and Dual Fuel Operating Conditions“

Dissertation thesis elaborated in the combined form of doctoral studies at the Department of Automotive, Combustion Engine and Railway Engineering, Faculty of Mechanical Engineering, CTU in Prague by Candidate:

Ing. Filip Černík

under the supervision of:

prof. Ing. Jan Macek, DrSc.

The present evaluation is based on the pdf version of the dissertation, created on March 13, 2018, 18:29:47.

The objectives of the present thesis can be summarized as follows: Assess the governing phenomena of combustion in large 2-stroke marine engines in both diesel and dual-fuel (DF) operation with a view to identifying simplified and hence fast, yet physics-based modelling approaches for the two combustion modes, integrate such models in a 1D simulation environment and demonstrate the potential of such enhanced simulations.
As regards diesel combustion, the challenge in modelling it lies in the admission of the fuel by means of multiple peripheral injectors with elaborate specification in terms of number, (large) size and orientation of the individual orifices into a strongly swirling environment, which triggers interactions of individual spray plumes unknown from other diesel engine types and becoming manifest in a very characteristic shape of the rate of heat release pattern.
In contrast, DF combustion involves significant complexity due the presence of two fuels – a small amount of liquid pilot fuel is injected into a pre-chamber to burn more or less same as in a conventional diesel engine – and the majority of the fuel input in the form of natural gas to be consumed in a lean premixed combustion mode. Such concept is not new but applying it to large, low-speed engines brings about new challenges: In particular, spontaneous ignition well before start of pilot fuel injection may occur and needs to be taken into proper consideration when aiming at a sufficiently generic modelling approach.
Based on the comprehensive evaluation of the particulars of the combustion system in such engines, which also included reverting to results from dedicated experimental investigations as well as detailed 3D CFD simulations, suitable concepts have been defined, implemented in GT-POWER and subsequently validated. The assessment of the combustion phenomena started from a thorough review of the key fundamentals of spray processes and the ensuing mixing-controlled consumption of the evaporated diesel fuel as well as of turbulent premixed combustion of natural gas, thereby giving due consideration to the specific features of and conditions prevailing in those engines. On this basis, new and pragmatic approaches have been found to describe the phenomenology of spray interactions in the diesel case and non-pilot-fuel-injection-based ignition in the DF case on the basis of suitably simplified considerations of dimensional aspects of the respective problems. The potential of the developed models is demonstrated extensively not only by means of a broad validation but also by providing examples of how they can be brought to productive use in complete system simulations and for assessing the implications of special operating conditions such as envisaged during engine transients.

Hence, the objectives of the thesis have been well achieved and its scope as well as the results obtained are partly even exceeding expectations.

The dissertation includes a fully adequate review of the state of the art in the field, reverting to the relevant literature, not only citing the well-known key researchers but also giving due attention to the work of various groups active in this area. Reference is made to a variety of parallel efforts made in recent years, thereby properly highlighting the particular value of the present approach. The discussion of the theoretical background is at an appropriate level and documents Mr. Černík's good understanding of the fundamentals as well as their application to the solution of the problems at hand. By nature, the present work is not targeting expansion of theoretical knowledge but aims at developing engineering tools for enhancing the development process. In fact, the accomplished integration of the models in a commercial 1D simulation platform holds the promise of facilitating the identification of most viable solutions and ultimately even their optimization.

In deriving the models, Mr. Černík has made excellent use of all kinds of data sources and techniques: On the one hand, results from computational investigations at different levels of detail ranging from detailed kinetics calculations of laminar flame speed to extensive CFD simulations of engine processes have been used for either the derivation of modelling concepts or the validation of specific models. On the other hand, data obtained in dedicated experimental studies of f.i. spray phenomena at relevant conditions were applied in the determination of key model parameters and the insight generated by e.g. endoscopic investigations of combustion in DF engines was instrumental for identifying a suitable concept for modelling self-ignition of the premixed charge. Finally, the wealth of experimental data from engine performance tests performed on various engines has not only been utilized as a basis for validation but also in order to derive a yet better understanding of governing phenomena. The successful final integration of the models in GT-POWER and the application in the validation as well as complete systems simulation studies demonstrates Mr. Černík's good command of programming skills as well as application know-how.

The present dissertation complies with the fundamental principles in terms of form, structure and scope of such document. The different parts related to the discussion of fundamentals, the derivation of the models and the presentation of results obtained are in good balance, though the sequence might have deserved second thought: Often it is advantageous to first present the theoretical background before discussing the state of the art. However, the different choice made here did not trigger redundancies and can hence be considered appropriate. Very obviously, Mr. Černík is not an English native speaker, as can be seen not only in a relative large number of typos, spelling and grammatical errors. Whereas the text in the more technical sections of the thesis is quite much to the point, formulations in other parts are sometimes clumsy and lacking conciseness. The list of references is quite extensive but cannot be considered exhaustive – there are examples in the text where reference is made to formulations or theories associated explicitly with particular researchers; however, without including the actual reference. More attention should have been paid to completeness and correctness of references (to bibliography entries as well as figures and equations) and typical copy-and-paste errors should have been fixed (caption of Figure 83). Equations are sufficiently comprehensive and clear to allow assessing the validity of the concepts, with only minor flaws (e.g. equation (118) not containing enthalpy flux terms related to fuel admission as well as flow at inlet ports and exhaust valve). The selection of figures is well suited for substantiating the essence of the dissertation, though some might also be considered almost redundant (e.g. Figure 79 vs Figure 80) or even seem to contradict each other (Figure 93 vs Figure 92). In summary, the thesis can be regarded as acceptable; however, in case actual publication is envisaged, non-negligible additional effort will be required to eliminate all remaining deficiencies.

In spite of this criticism related to formal aspects I fully support admission of the candidate to the final defense presentation. He has demonstrated his ability to apply a scientific approach to tackling a technical problem of substantial scope and to put in place viable engineering solutions on the basis of innovative concepts for reducing the complexity to such extent that the result can be used in developing and optimizing future propulsion systems based on large two-stroke diesel and dual-fuel engines. Without any hesitation I recommend that Mr. Černík is awarded the doctoral degree on the basis of his achievements documented here.