Review of Doctoral Thesis

Author: **Ing. Zdeněk Žák**
Title: **A 1-D Unsteady Model of a Twin Scroll Radial Centripetal Turbine for Turbocharging Optimization**
Reviewer: **Jiří Navratil, Ph.D.**

The Ph.D. candidate describes the development of a map-less approach and validation of a state of art twin-scroll radial turbine model covering detailed geometry modeled in 1-D software code working properly in both steady state and transient operating conditions.

The first part of the thesis describes a collaborative project dealing with a turbocharger test rig development capable to measure the performance of the twin-scroll turbine under steady flow with the different level of the impeller admission. The test bed is placed at ČZ a.s. Turbo division in Strakonice, Czech Republic. It is shown that the laboratory of the turbochargers with single combustion chamber has been enhanced for the twin-scroll testing operation. The new test rig allows measuring under the full, partial, fully blocked admission of the impeller or both scrolls interaction flow. A single natural gas burner feeds both turbine entries. The measurements have been undertaken for various BSRs. An automated test data recording allow efficient post-processing and additional data calculation. The following section focuses on a 6 cylinder diesel engine testing. The steady state complete engine characteristic has been obtained. The next chapter describes creation of the turbocharger engine test rig model with following the same tested procedure. A twin-scroll turbine model is built up from specific pieces (entry sections, nozzle impeller, leakage areas and turbine outlet) constructed within 1-D gas thermodynamic code. The model is validated using several expansion ratio based tuning coefficients at various turbocharges speed and BSRs. Similarly, building up and validation of the diesel model in 1-D gas code is described. A simple TPA method is used for burn rate calculation. The baseline model validation is performed using a simple turbine model with two entries connected together with a fixed diameter orifice. The turbine model is further replaced by the new 1-D map-less turbine allowing reverse turbine scroll flow proving a good correlation with the test data focusing on crank angle based turbine pulsations. The last section concentrates on a transient engine regimes (at constant engine speed) modelling showing some offsets vs. transient test data.

The main contribution of this doctoral thesis stays in the detailed description of the twin-scroll 1-D mass-less turbine model development and its validation. The steady state crank angle based simulation results show a good correlation between turbocharger test rig and chosen diesel engine data, allowing detailed insight and understanding of the specific turbine geometry flow behavior. I appreciate, that the postgraduate student refers to other projects and studies – using their results as a starting point for this thesis. I am not entirely happy with the transient regimes correlation. There can be a boost pressure over-prediction seen at most of the tested engine speeds. I cannot quite agree with a statement on page 15: "Today, the development of 1-D unsteady flow solver is almost finished." In my opinion, this thesis confirms the opposite. The automotive industry feels increased pressure to quickly deliver validated accurate and predictive real-time 1-D engine models for their usage in MiL, SiL and HiL systems to speed up development and to reduce a combustion engine development cost. The presented 1-D turbine model is really amazing. In my opinion, it might be beneficial to show a scheme of a control network connected to the turbine geometry elements.

The thesis is ok from a formal point of view. It might be beneficial to reduce number of standalone plots, potentially merging some of them together. I appreciate, that it is written in English, and so it can be studied or used as a reference by non-Czech speakers. In my opinion, this thesis fulfills all conditions for gaining the Ph.D. degree, therefore it is **recommended**.

Prague, 20th March 2018 Jiří Navrátil