Review of the Doctoral Thesis

1-D Unsteady Model of a Twin Scroll Radial Centripetal Turbine for Turbocharging Optimization

Submitted to the Faculty of Mechanical Engineering, Department of Automobiles, Internal Combustion Engines and Railway vehicles of Czech Technical University in Prague

by **Ing. Zdeněk Žák**, Faculty of Mechanical Engineering, Department of Automobiles, Internal Combustion Engines and Railway vehicles of Czech Technical University in Prague

Supervisor: Prof. Ing. Jan Macek, DrSc.
Supervisor specialist: Doc. Ing. Oldřich Vítek, Ph.D.

Research work described in the submitted Doctoral Thesis develops physical based predictive simulation model of the Twin Scroll Turbocharger, a unique methodology and tool considering industry standard map based approach. Details of the unsteady model for plug and play simulation with the internal combustion engine model in a 1-D simulation software are described considering rich literature research and technical papers published by Ing. Žák at renowned conferences and journals. Modular 1-D twin scroll turbine stage model, prepared in GT-Suite environment, is based on the Euler turbine theorem and considers transformation of the total state from stator to rotor using velocity triangles at the impeller inlet/outlets together with mixing phenomena and leakages.
A specific gas stand test rig has been developed allowing measurement unequal flow conditions at the turbine stage inlet to correlate and confirm developed map less model as well as for further R&D projects. Engine tests were conducted on a tractor type 6-cylinder diesel engine to confirm the 1-D turbine stage model under the steady state and transient unsteady operations.
Developed virtual turbine stage enables sensitivity study of design parameters and dimensions for better understanding their implication on engine and turbo performance in the early stage of the powertrain development. Methodology also helps reduce amount of measured operation points of the multi entry turbine stages on the gas stand test rig and enables extrapolation measured points to the standard turbine stage maps.
Doctoral thesis meets all objectives set at the beginning of the work and Ing. Žák demonstrated his ability and dedication to process heavy and cross functional topics in a scientific way with high quality. Citations of his research in work of others (journals, SAE, Ph.D., M.S., etc.) confirm Ing. Žák's knowledge, reputation and novelty of his 1-D Twin scroll Turbine stage model.
Thesis, written in English, is well structured, accompanied with fundamental equations applied in the developed 1-D model together with illustrative figures and diagrams well placed in the flow of the text. Therefore, I am recommending the Doctoral Thesis for defense presentation.

Following paragraph list possible discussion topics during the defense presentation I would be interested in.
Apparently, less nr. of turbocharger operation points can be measured using developed model. Could Ing. Žák quantify possible saving potential (hours, % nr. of operation points vs. map based

reference, …)? Are the two compressor stages and blocked turbine wheel measurements as used in the Thesis always needed for the turbine stage model calibration?
Does the level of the partial admission vary with the nr. of cylinders or exhaust manifold design? If so, can Ing. Žák indicate admission level for instance for 4-cyl. vs. 6-cyl. engine to assist with better targeting the most important turbine stage operation conditions?
How has the flow mixing or communication between the scrolls been correlated to the gas stand or engine tests? Considering gasoline engine and its sensitivity to knocking, does the model enable analysis of the communication sensitivity on the engine performance? Could Ing. Žák elaborate on the pros and cons of the turbine stage with the parallel sections (meridionally divided) versus double volute (sector/segment division) design? Considering gasoline engine and endeavor for maximizing low end torque performance, transient response and focusing part load operation with advance combustion (EGR, Miller, Lean,..), could Ing. Žák comment on priority regarding each of the following parameter: should the turbo target rather excellent separation on cost of efficiency or is it better to strive for excellent efficiency on cost of separation and inertia? Could such trade-off curves be found on the combustion engine with the developed model?

Brno, 26th March 2018

Ing. Luděk Pohořelský, Ph.D.
Engineering Manager
Honeywell Transportation Systems
Tuřanka 100
Tel. +420734685982
email: ludek.pohorelsky@honeywell.com