Conjugate Heat Transfer Analysis of a Centrifugal Compressor for Turbocharger Applications

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Long Abstract

Introduction

For many years, turbocharging has been one of the key technologies for achieving high specific power output of internal combustion engines taking also into account more and more stringent emission limits. Additionally, car manufactures attach high importance to a good drivability, which usually is being quantified as a target torque already available at low engine speeds that is fast reached in transient response operation.

High specific power output requires high boost pressures. This can be achieved using a single stage turbocharger but with an inacceptable penalty in transient engine operation (1). Therefore, for highly downsized engines, 2-stage turbocharging systems (R2S) are applied in order to overcome the conflict of high specific power and simultaneously low specific fuel consumption in agreement with the emission legislation.

In case of R2S turbochargers, for the high-pressure compressor wheel, the load in terms of temperature can be significantly higher than in the single stage case. Therefore it is important to take into account the influence of high compressor wheel temperatures on durability in the design process.

In the current paper, a conjugate heat transfer analysis (CHT) for predicting the temperature load on compressor wheels for turbochargers is presented.

The numerical model was validated by experimental data. For the validation, a R2S turbocharger for commercial vehicle applications was mounted on a gas stand test rig. The high pressure compressor was instrumented with thermocouples for measuring the temperatures on the volute, the compressor back plate, the bearing housing and on the compressor wheel. The measurement locations on casing and back plate are shown in Figure 1. These were used for deriving boundary conditions for the numerical model.

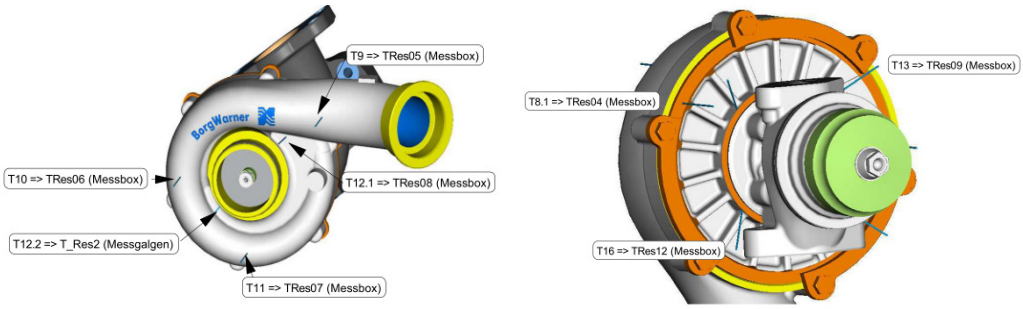

Figure 1. Position of thermocouples on volute casing

For the compressor wheel, temperature was measured at 7 locations (Figure 2), at the tip of the compressor wheel (1), at the fillet of the blades (2), at the back side of the wheel (3 and 6) close to the bore of the compressor wheel (4 and 5) and at the shaft(7).

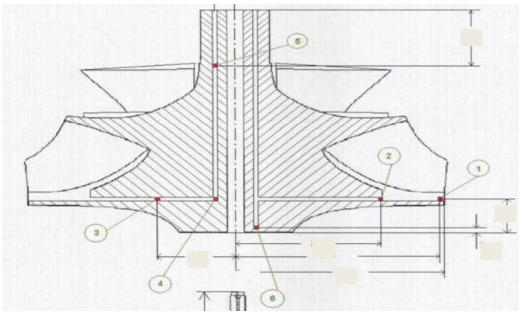

Figure 2. Position of thermocouples on compressor wheel

The signals of the thermocouples located in the compressor wheel were transferred via a telemetric system to the data acquisition board. For the measurements, operating points which are typical for the high pressure stage of R2S turbochargers were investigated. Of particular interest are operating points with high wheel temperatures resulting from high compressor inlet temperatures and/or high pressure ratios. The drawback of the telemetric system is that the compressor speed is limited to 140000 rpms. Therefore it is not possible to acquire temperature data of the compressor speed in operating points with high speeds and high temperatures which belong to the most interesting in terms of durability.
For the CHT analysis, only the compressor side of the high pressure turbocharger including the piping between the stages was modeled (Figure 3). The simulations were run steady state using the frozen rotor and the k-ω-SST turbulence model.

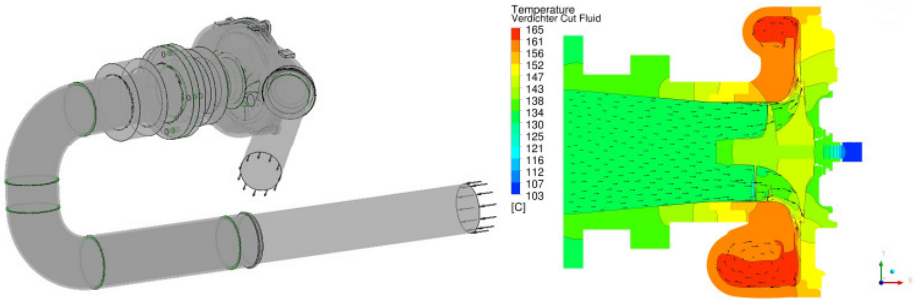

Figure 3: CHT model of high pressure compressor

The intention of the CFD model is to get a deeper understanding of the heat transfer in the high pressure compressor stage, to extend the range of operating points to higher compressor speeds which cannot be covered by the telemetric system and to learn how to create a reliable CHT-model in order to investigate other compressors in the future, where no telemetric measurements are available or possible. The latter one is escpecially important for passenger car applications where the thermocouples and telemetric system cannot be installed due to the smaller compressor wheels.
In the final paper, the setup of the experiments and the numerical model will be presented in detail. Also the heat transfer in the compressor stage, will be discussed in two selected operating points.

References

[1] **Guilain, S., et al., et al.** *Optimization of a small two-stage turbocharged Diesel Engine.* Dresden, Germany : Aufladetechnische Konferenz, 2006.