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# Automotive turbochargers power estimation based on speed fluctuation analysis

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**Abstract**

Turbocharging technology will play a crucial role in the near future as a way to meet the requirements for pollutant emissions and fuel consumption reduction.
However, optimal turbocharger control is still an issue, especially for downsized engines fitted with a low number of cylinders. As a matter of fact, automotive turbochargers are characterized by wide operating range and unsteady gas flow through the turbine, while only steady flow maps are usually provided by the manufacturer. In addition, in passenger cars applications, real-time turbocharger optimal control is even more difficult because of the lack of information about pressure/temperature in turbine upstream/downstream circuits and turbocharger rotational speed.
In order to overcome these unknowns, this work presents a methodology for instantaneous turbocharger rotational speed determination through a proper processing of the signal coming from one accelerometer mounted on the compressor diffuser, or one microphone facing the compressor. The presented approach can be used to evaluate both turbocharger speed mean value and the amplitude of turbocharger speed fluctuations caused by the pulsating gas flow in turbine upstream and downstream circuits. Once turbocharger speed has been determined, it can be used to estimate power delivered by the turbine.
The whole estimation algorithm has been developed and validated for a light duty turbocharged Common-Rail Diesel engine mounted in a test cell. However, the developed methodology is general and can be applied to different turbochargers, both for Spark Ignited and Diesel applications.


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## 1. Introduction

Due to the increasing request for pollutant emissions and fuel consumption reduction, the optimization of turbocharger control has become a critical issue in modern engine management systems. Prior research demonstrates that pollutant emissions reduction and higher engine efficiency can be achieved through a proper combination of turbocharging technique and engine downsizing [1]. However, turbocharger optimization is a critical task, mainly due to the few quantities related to turbocharger operating conditions that can be directly measured on-board. Moreover, optimal turbocharger control becomes even more difficult when turbochargers work over a wide operating range, since turbocharger manufacturers usually provide only steady flow maps that do not cover low rotational speeds (that may become predominant in standard driving cycles) [2]. Another important aspect to be addressed, especially for turbochargers coupled to downsized engines with a reduced number of cylinders, is the lack of information about unsteady operating conditions, since only steady flow maps are usually available for compressor and turbine [3].

In order to optimize turbocharger control, this work presents a methodology that allows extracting information about turbocharger operating conditions through a proper processing of the signal coming from one accelerometer mounted on the compressor diffuser or a microphone facing the turbocharger. In particular, the developed methodology is suitable for the estimation of both turbocharger rotational speed (mean value)and the amplitude of its instantaneous oscillations. Then, such oscillations can be used as an indicator of power delivered by the turbine. The whole methodology has been developed for a 4-cylinder Common-Rail light-duty Diesel engine installed in a test cell at the University of Bologna.

Many works, carried out over the past years, demonstrate that turbocharger speed can be estimated through a proper processing of vibration [4] or acoustic emission signals [5]. The main limitation of these methodologies consists in the fact that only turbocharger speed mean value can be estimated, while no information about the amplitude of speed fluctuations can be extracted. However, the on-board knowledge of this quantity would be very important to compensate the effects due to pulsating flows, such as errors in maps interpolation/extrapolation [6] or instabilities at low flow range [7]. Furthermore, this work demonstrates that real-time knowledge of turbocharger speed fluctuations provides information about turbine power, which could be a useful feedback for an optimal turbocharger control strategy.

**Nomenclature**

| | |
|---|---|
| $\overline{\boldsymbol{\omega}}_{TC}$ | Turbocharger average speed |
| $J_{TC}$ | Turbocharger inertia |
| $\dot{\boldsymbol{\omega}}_{TC4}$ | Turbocharger acceleration order 2 component |
| $\boldsymbol{\omega}_{TC4}$ | Turbocharger speed order 2 component |
| $\omega_{TC}$ | Turbocharger speed |
| $\omega_{eng}$ | Engine rotational speed |
| $\gamma$ | Specific heat ratio |
| $T_3$ | Temperature in the turbine upstream circuit |