

Investigations of Automotive Turbocharger Acoustics

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ABSTRACT

In this paper an overview of recent experimental studies performed at KTH on the sound transmission and sound generation in turbochargers is presented. The compressor and turbine of the turbochargers are treated as acoustic active 2-ports and characterized using the unique experimental test facility established at KTH. The 2-port model is limited to the plane wave range so for higher frequencies the propagating acoustic power is estimated using an average based on pressure cross-spectra. A number of automotive turbochargers have been studied for a variety of operating conditions systematically selected from the compressor and turbine charts. The paper discusses the experimental procedures including special techniques implemented to improve the quality of the data. Results from a number of experiments on various modern automotive turbochargers including a unit with variable turbine geometry (VTG) are presented.

1. INTRODUCTION

Turbochargers are an important part of most modern automotive high efficiency engines. Nowadays almost all the automotive and industrial diesel engines produced and the vast majority of high performance SI engines are turbocharged. Naturally, the acoustics of turbochargers has therefore also become an issue.

Exhaust gas driven turbochargers consisting of turbine and compressor are used to increase the thermodynamic efficiency of an IC-engine. It is achieved by supplying air to the engine at higher pressure and therefore allowing cylinders to be filled with more combustible mixture by using the energy available in the exhaust gas (see Fig. 1). Modern turbochargers are typically equipped with variable geometry

turbines (VTG) which offer adaptability and higher efficiency for a variety of operating conditions.

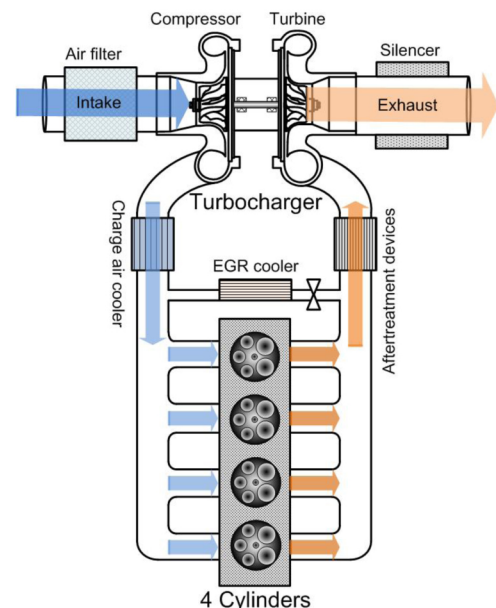


Figure 1. A simplified schematic representation of the turbocharged IC-engine.

Turbocharger compressors are generally centrifugal compressors consisting of a wheel, diffuser and housing. As the compressor wheel rotates, ambient air is drawn in axially through a filter-silencer system, accelerated to high speed and then expelled in a radial direction to the outlet which normally leads to an intercooler.

Both the turbine and the compressor have an influence on how the low frequency engine pulsations propagate in the intake/exhaust system i.e., the scattering of incident pressure

pulses or waves from the unit. This is referred to as the *passive acoustic* property of the turbocharger. If linear acoustic models are applied the passive properties can in the plane wave range be described using two parameters: the reflection coefficient and the transmission coefficient or alternatively the transmission loss.

A turbo-unit also produces high frequency aerodynamic sound, which is referred to as its *active* ("sound generating") *acoustic* properly. The sound field in a duct system coupled to a turbocharger depends on both the passive and active properties of the device.

According to Lighthills classical theory there are three basic mechanisms that can create sound in a fluid: i) fluctuating volume flow - monopole type of source; ii) fluctuating surface pressures - dipole type of source and iii) free turbulence - quadrupole type of source.

In a rotating machine, such as a turbocharger, the blades will generate a monopole type of source only when the blades move close to the speed of sound or supersonically. In the supersonic case there will also be rotating shock waves attached to the blades. The spectrum of the monopole contribution will in the supersonic case be harmonics of the rotation frequency f_0 . This type of rotating shock wave noise is referred to as buzz-saw noise and exists for instance on modern aero-engines. Supersonic tip speeds are also common for modern high speed turbo compressors.

A number of dipole or fluctuating pressure sources can be found in rotating machines. One is the blade pressure. The most important contribution to time varying blade pressures is inflow disturbances. These can be of two types: stationary and non-stationary flow distortions, e.g., turbulence. The stationary distortions will lead to periodic acoustic signals and the turbulence to a broad band signal. The periodic signals will consist of harmonics of the blade passing frequency (BPF). Without inflow disturbances these tones are referred to as rotor-alone tonal noise. A second source of dipole noise on rotating machines is rotor-stator interaction, e.g., fluctuating pressure fields created by interaction between inlet/outlet guide vanes and the rotor. This noise is also periodic in time and consists of harmonics of the BPF. Finally the turbulence in the flow will act as a broad band acoustic source but normally this source is not important unless the flow forms a jet with a Mach-number close to 1. This quadrupole type of source is normally important only at the outlet of jet engines and high pressure valves, but for turbochargers it is of little interest. In general the influence of turbocharger noise has been reported to be more important on the intake, i.e., compressor side, mainly because of the relatively good damping characteristics by modern mufflers on the exhaust side.

Based on the above discussion the main aerodynamic noise generating mechanisms in turbo-compressors are: tonal noise at blade passing frequencies, buzz-saw noise and blade tip clearance noise.

In [1] a review about the major fundamental investigations in the field of turbocharger acoustics was published by Råmmal and Åbom. This paper was followed by the first systematic experimental investigation [2] on the sound transmission in a turbo-compressor working at realistic operating conditions by the same authors. In [3] the experimental results presented in [2] for automotive turbo-compressors were compared to the simulated 2-port data obtained from a 1-D wave model with a good agreement in the low frequency region. To the authors knowledge it was the first effort to implement a simple 1-D wave model for prediction of the acoustic two-port data of an automotive turbo-compressor working at realistic operating points.

Recently the first successful experimental characterization of the complete turbocharger was published [4]. Both the turbine and the compressor side were studied in up- and downstream directions under various operating conditions for a 3 different automotive units. General conclusions for the behavior of the transmission loss as a function of frequency were presented based on the results.

The aim of the present paper is offer an overview of the most important findings from the investigations of automotive turbocharger acoustics carried out at KTH including the recent developments and improvements in the experimental procedures. In particular measurement of active data or sound power spectra will be discussed and some results presented. Also for the passive part the possibility to develop quasi-stationary models is discussed. An important part of such models are the losses that occur in the turbocharger unit. Methods to estimate such losses using acoustic 2-port data are also addressed.

2. INVESTIGATION METHODS

This section presents an overview of the state of the art methods recently tested and developed in KTH for experimental investigations of turbocharger acoustics. To the authors knowledge the unique turbocharger acoustics test rig described in section 2.1 represents the currently most advanced experimental setup for the complete acoustic characterization of automotive turbochargers.

2.1. THE EXPERIMENTAL FACILITY

The turbocharger characterization facility has been established at the research competence centre for investigations on IC-engine gas management at KTH in Stockholm. The ambition was to develop accurate experimental procedures for the determination of the

scattering data for automotive turbochargers at realistic operating conditions selectable from the compressor and turbine charts. Additionally to the measurements for the passive data, the facility can also be implemented to measure the sound generation by the turbo unit (the active properties).

Hereby an overview together with the latest modifications for the experimental procedures to determine the sound transmission through and sound generation from a working automotive turbocharger compressor and -turbine is given. The current layout of the rig is schematically presented in [Fig. 2](#) and illustrated by photo composition in [Fig. 3](#) and. The rig has two distinct sides: the compressor side and the turbine side, which can both be investigated at any operating conditions selectable from the manufacturers operating charts.

The air mass flow (up to 0.5 kg/s) used to drive the turbocharger turbine originates from two remotely located industrial compressors. The installation has been designed to provide stable inflow conditions (up to 6 bars and pressure fluctuation less than 1%). In order to provide higher inflow temperatures into the turbocharger turbine, an 18kW custom made electrical heater is used, capable of raising the air temperature at least up to 100°C for the highest mass flows. The turbine inflow as well as the boost pressure in the compressor outlet pipeline is regulated from the operators control module (LabVIEW virtual instrument, see [Fig. 4](#)) by implementing electronically controlled and pneumatically operated ball-valves (SOMAS A13-DA). An autonomous portable lubrication rig is used to supply pressurized oil flow to the turbochargers tested at the acoustics facility. The oil flow is required to provide optimal lubrication and cooling for the turbocharger bearings.

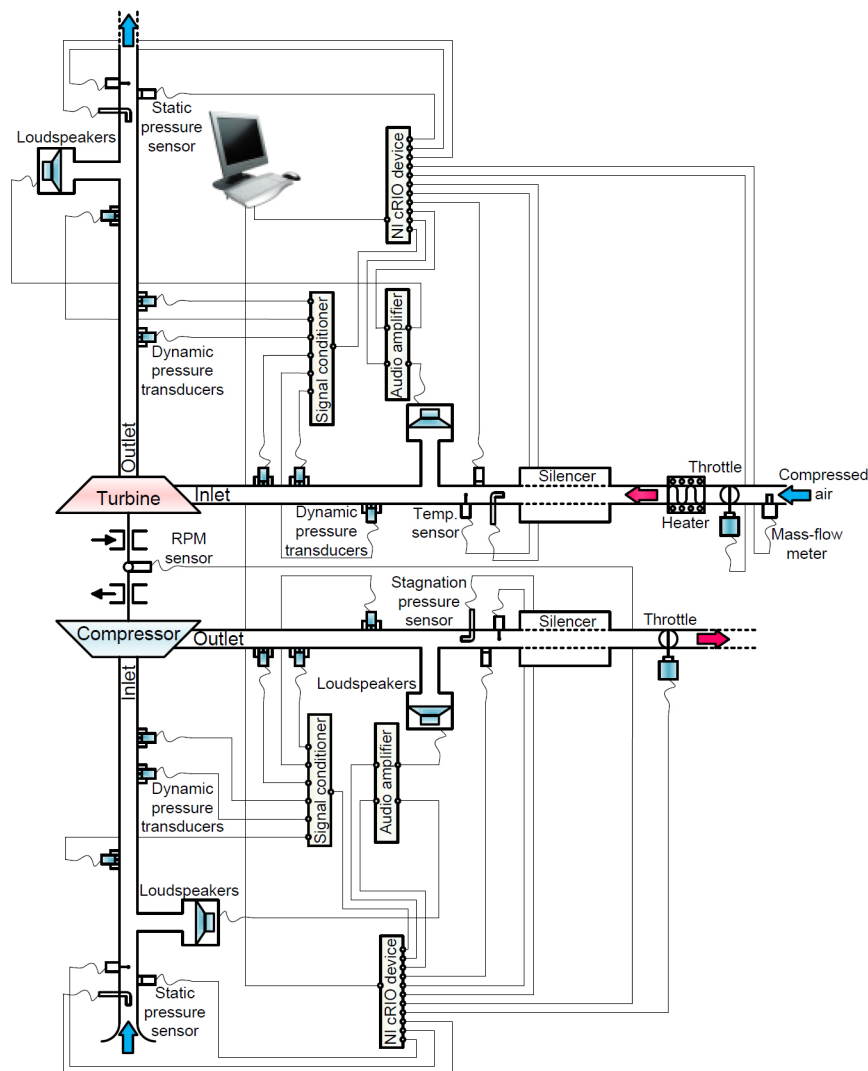


Figure 2. A schematic representation of the test facility in KTH designed for investigations of automotive turbocharger acoustics.

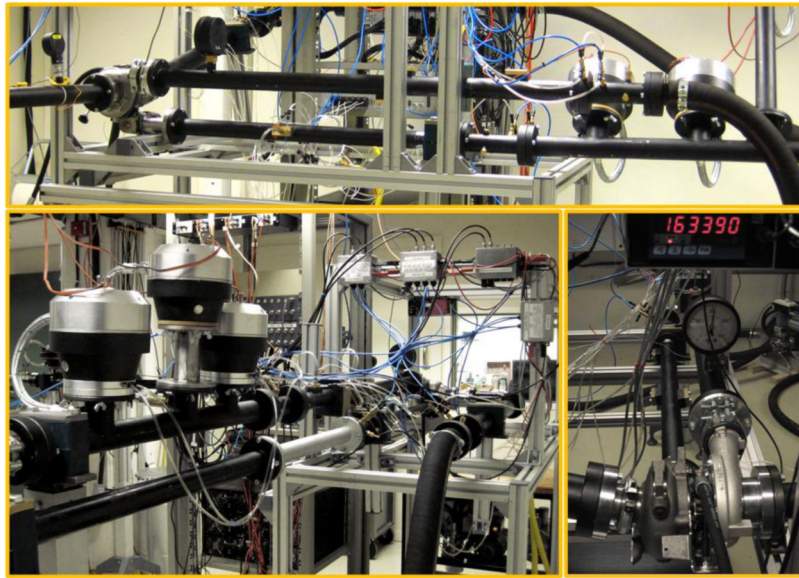


Figure 3. Photos of the test facility in KTH implemented for investigations of automotive turbochargers.

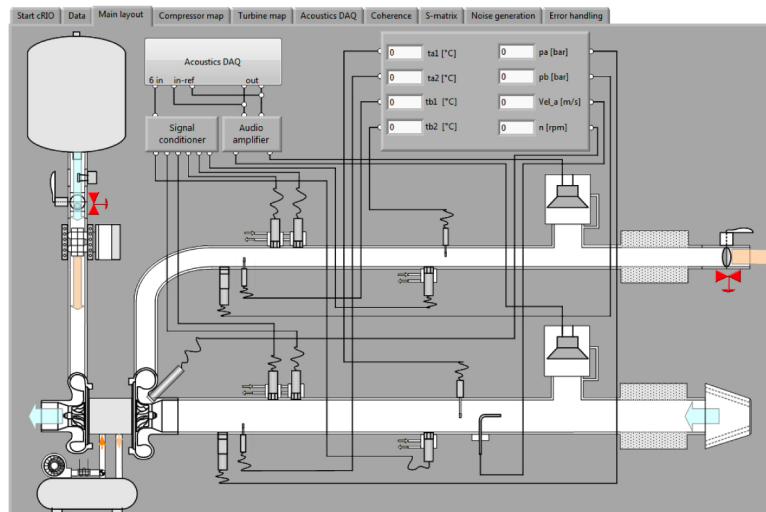


Figure 4. An example screenshot of the custom built data acquisition and control board programmed in LabVIEW.