

Turbocharger Noise Quality Parameters for Efficient TC Noise Assessment and Refinement

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ABSTRACT

Due to more challenging future emission legislations and the trend towards downsizing, the number of turbocharged (TC) engines, especially petrol engines, is steadily increasing. The usage of TC has high risk to cause different noise phenomena apparent in the vehicle interior which are often perceived as annoying for the passengers.

In order to further improve consideration of TC topics in the development, objective judgment and monitoring of TC noise issues is of high importance. Therefore, objective parameters and corresponding tools that are especially focusing on TC noise phenomena have to be developed.

One main target of these tools is to deliver an objective TC assessment in an efficient way and with minimum additional effort. Application of the criteria presented in this publication therefore allows acoustic engineers to judge the NVH behavior and annoyance of the TC with respect to its vehicle interior noise contribution. Based on this assessment TC noise issues can be detected efficiently and appropriate noise reduction measures can be derived accordingly.

Main focus of this publication is to explain the introduced parameters. For further clarification, an example which demonstrates the possible usage of TC noise quality parameters during the development will be presented.

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INTRODUCTION

Because of the character of turbocharger related noises, it is difficult to estimate their influence on the interior noise with simple loudness measurements. Therefore it is necessary to implement objective parameters which assess the noises from a psychoacoustic point of view. These noises often have low sound pressure levels compared to other sources in the vehicle, but are still annoying for passengers due to their frequency range and occurrence during part load operating conditions.

Therefore a methodology which detects these noises, associates them to the different turbocharger noise phenomena and judges their annoyance, allows objective sound quality monitoring during the development process.

This assessment should be possible with only minor additional effort in terms of measurement equipment and operating conditions.

Furthermore the usage of measurement data which is captured during vehicle measurements, either on chassis dyno or test track, is a main feature of the methodology.

OVERVIEW

To explain the idea and the procedure of the turbocharger noise assessment and the corresponding noise quality parameters the content of this paper is the following:

- Overview of the different turbocharger related noise phenomena which are considered in the process.
- Description of the basic approach to detect and judge TC noise phenomena.
- Detailed explanation of the procedure with focus on one example phenomenon, the parameter calculation based on certain algorithms and the objective rating.
- An example showing the possible usage during a vehicle development process.

TURBOCHARGER NOISE PHENOMENA

In the past turbocharger noise phenomena were already categorized into different groups with reference to their frequency range, cause and effect etc. [1] [2]. As shown in [Figure 1](#) the main focus lies on six phenomena which are divided in two major categories:



- Tonal noises which are mostly following the turbocharger speed (except the constant tone phenomenon) and are directly related to the TC
- Broadband noise phenomena which are non-synchronous and can be related to the TC and to the intake system of the powertrain

	Phenomenon	Category	Frequency
Sub-synchronous	Constant Tone	Tonal, almost constant	400 Hz – 1000 Hz
Synchronous	Unbalance Whistle Noise	Tonal, 1 st order	500 Hz – 4000 Hz
Super-synchronous	Blade Passing Noise	Tonal, depending on number of blades	< 20 kHz
	Ball Bearing Noise	Tonal, depending on bearing geometry	< 20 kHz
Non-synchronous	Flow Noise	Broadband	300 Hz – 20 kHz
	Let Off Noise	Broadband	< 20 kHz

Figure 1. Overview Turbocharger Noise Phenomena

Constant Tone

The constant tone phenomenon is a tonal noise of almost constant frequency which is not proportional to the turbocharger speed. At low speed it is slightly increasing until it reaches a quite constant frequency typically arising from a resonance of the rotor shaft in its bearings. This frequency is depending on the bearing situation, oil viscosity and temperature and is typically slightly below 1 kHz for passenger car turbochargers. In Figure 2 a typical constant tone phenomenon during an engine speed run-up can be seen.

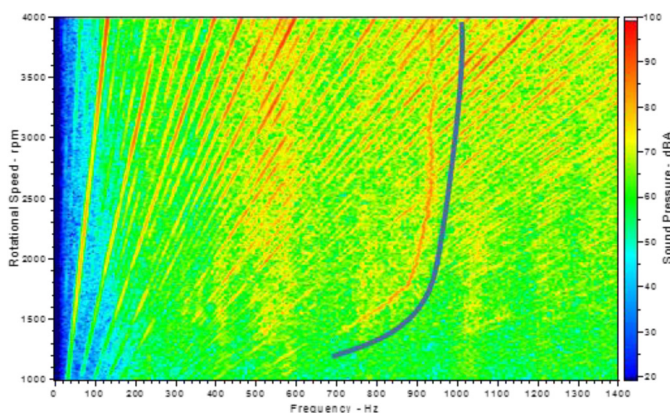


Figure 2. Constant Tone at the Intake Orifice Measurement Position

Unbalance Whistle Noise

Unbalance whistle noise like shown in Figure 3 is synchronous to the turbocharger speed (1st order of rotor speed). It occurs due to the unbalance of the TC rotor itself and therefore the level is increasing with TC speed. Typical frequency range of this phenomenon is between 500 and 4000 Hz. The unbalance whistle noise is also used to calculate the turbocharger speed which is an important input for further investigations. Usually this phenomenon is most critical during a coast down after a full load acceleration.

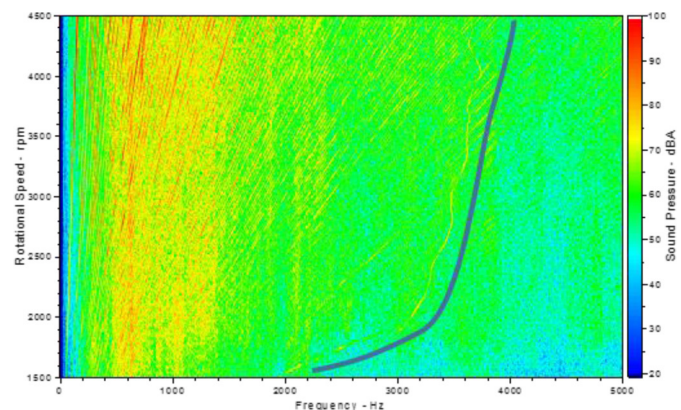


Figure 3. Unbalance Whistle at an Engine Compartment Measurement Position near the Firewall

Blade Passing Noise

Blade passing noise is also a tonal phenomenon which is depending on the turbocharger speed and on the number of blades of the turbine and compressor wheel. Reason for the noise is the blade passing through irregularities in the stationary flow. The frequency is proportional to the speed times the number of blades. Therefore the phenomenon often lies in the non-audible frequency range for high load operating conditions, nevertheless it can be annoying during part load or steady state conditions. In Figure 4 a typical blade passing phenomenon during an engine speed run-up with high load is shown. In this case, the acceleration of the turbocharger at the beginning of the ramp can be audible and therefore annoying for passengers in the vehicle.

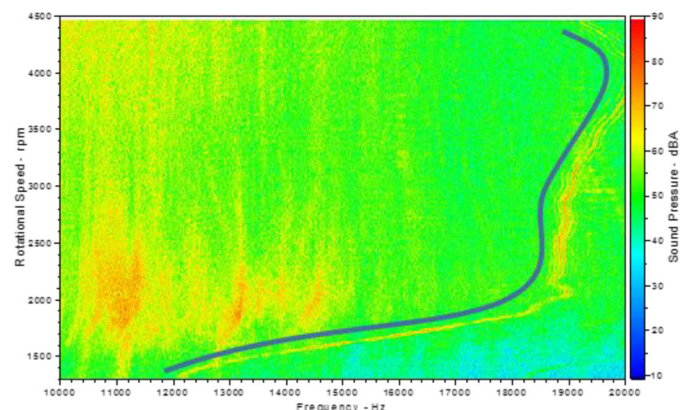


Figure 4. Blade Passing Noise at TC Near-field Measurement Position

Ball Bearing Noise

Due to the fact that ball bearings can provide an improvement to the turbocharger throttle response and performance this bearing system is getting more and more interesting, especially for sports cars.

Nevertheless this also brings new challenges to acoustic engineers since ball bearings can generate different sound and vibration phenomena [3]. Generated frequencies are synchronous to the turbocharger speed and depend on the bearing geometry. If the specifications of the bearing are known, the phenomena can be assigned to the single elements of the bearing (e.g.: inner and outer

ring, rolling element). These specifications are: number of rolling elements, diameter of rolling elements, pitch circle diameter of rolling elements and the contact angle.

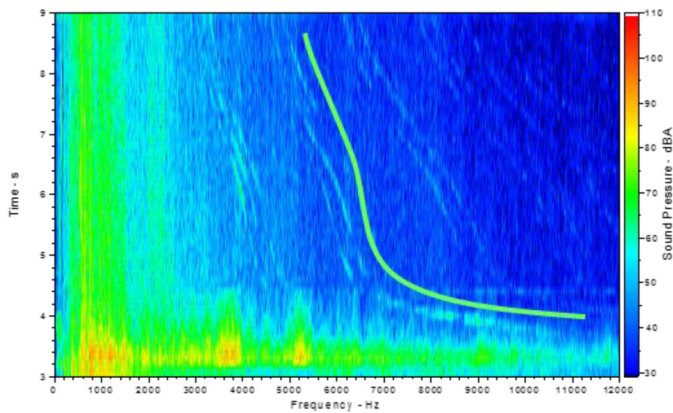


Figure 5. Ball bearing noise at vehicle intake orifice measurement position

Similar to blade passing noise, ball bearing noise may lie in higher frequency ranges but also in lower range noise issues caused by the bearing are possible. Critical operating conditions for ball bearing noise are coast downs after engine speed run-ups with high load. Also tip-in maneuvers in idle condition or at low speeds, like shown in [Figure 5](#), can be critical for ball bearing noise.

Flow Noise

There are several reasons for flow noise excitation in combination with turbocharged engines.

Flow noise occurs when the compressor operates close to the surge limit or even beyond, due to turbulences at compressor blades and flow direction inversion. It is a broadband phenomenon and can take place in a wide frequency range from about 300 Hz onwards on low and high pressure side of the turbocharger. An example is shown in [Figure 6](#).

Furthermore edges, gaps and sharp diameter changes in the intake system, air-filter housing or intercooler can also lead to high flow noise. In this case most critical are operating conditions with high flow-rates.

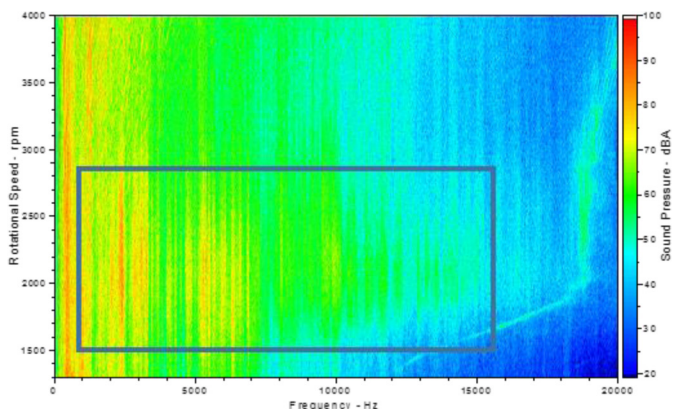


Figure 6. Flow Noise at Intake Orifice Measurement Position

Let Off Noise

This category includes all noises which occur after a sudden pedal release. In case of such event, different noises can occur depending on the boost pressure control mechanism of the turbocharger.

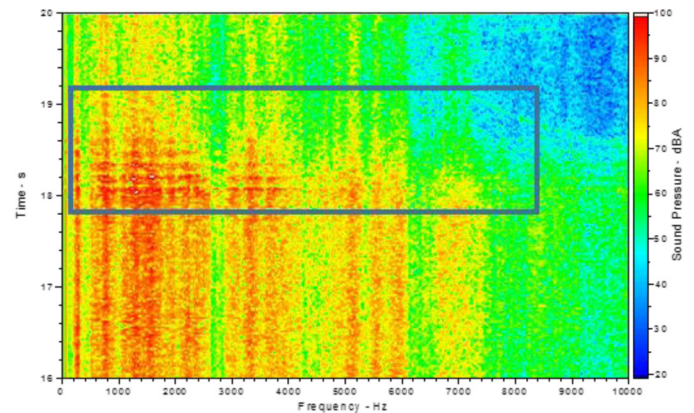


Figure 7. Surge noise at intake orifice measurement position

For example a significant surge noise can occur (see [Figure 7](#)) or flow noise in the waste-gate or blow-off valve can become audible (see [Figure 8](#)). Also the frequency of such phenomena strongly depends on the origin and therefore covers a wide range.

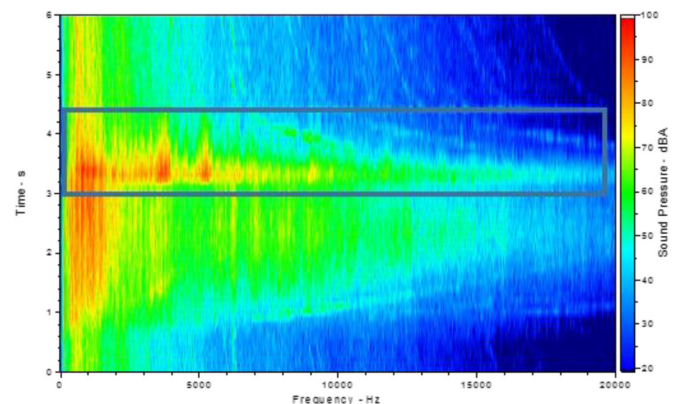


Figure 8. Let off noise at intake orifice measurement position

BASIC APPROACH TO DETECT AND JUDGE TC NOISE PHENOMENA

As shown in [Figure 9](#), the basic approach to detect and judge turbocharger noise phenomena consists of four major steps.

- Measurement of input data
- Detection of turbocharger related phenomena
- Parameter calculation
- Objective rating