Chapter 2
Induced Noise Types

Noises, as shown in Fig. 2.1 induced in automotive turbochargers are normally classified into the following different types of noises [1, 2].

Pulsation whistle is caused by slight differences in the compressor wheel chamber volumes due to milling or molding process variations. Its frequency ranges from 1,200 to 4,500 Hz and occurs at engine speeds from 1,500 to 3,500 rpm, usually in second gear with high load. It is also dependent of the number of these unequal compressor wheel chambers.

Rotational noise (rotating-blade-related noise) is generated by the rotating blades of the compressor or turbine wheels at an engine speed range from 1,400 to 2,500 rpm in second and third gears. This noise has very high frequencies between about 8 and 18 kHz or higher, which result from the number of blades and rotor speed. Although adult human ears cannot recognize noise higher than 16 kHz, animals in the car could hear such high frequencies.

Growling noise (compressor-stall-related noise) is induced by the partial reversal of the charge air in the compressor wheel. Partial flow separation at the suction side near the blade outlet causes the growling noise. Its frequency ranges in a wide band between 1,200 and 3,500 Hz containing partly metallic noise, and occurs at engine speeds between 1,400 and 2,500 rpm in second and third gears. Growling noise propagates in the direction of the compressor outlet, and the charge-air intercoolers.

Whining noise (compressor-surge-related noise) is induced by a deep surge condition in the compressor wheel where the charge air totally recirculates from the compressor outlet to compressor inlet. The whining noise occurs when driver suddenly releases the gas pedal, causing the required charge-air mass flow rate for the engine to be suddenly reduced at still high turbocharger speeds. This leads to the deep surge working condition in the compressor. Its frequency ranges in a wide band from nearly 800 to 2,700 Hz containing partly metallic noise, and occurs at engine speeds from 1,400 to 2,500 rpm in second and third gears. Whining noise propagates in the direction of the compressor inlet and the air filter system.

Unbalance whistle is caused by the unbalanced rotor and unbalance change of the rotor after a long-term operating time. Its harmonic frequency (1X) is between

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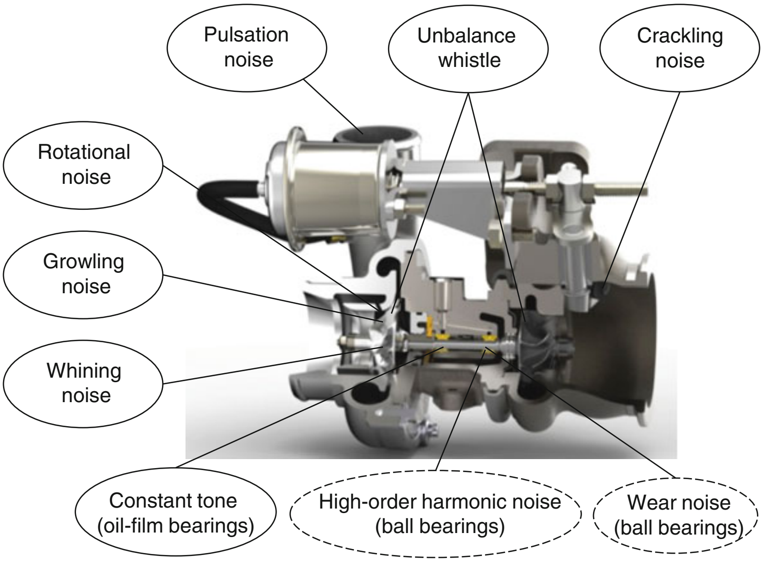

Fig. 2.1 Induced noises of automotive turbochargers

1,200 and 4,500 Hz happening at an engine speed range between 1,500 and 3,500 rpm in second gear at relatively low loads.

Constant tone (howling) is induced by the inner oil whirl due to oil whirling in the oil-film radial bearing; its frequency lies between 600 and 1,000 Hz in the human audible range. The inner oil whirl frequency order in the rotating floating ring bearings reduces from about 0.4 to 0.3X as the rotor speed increases. Therefore, the inner oil-whirl induced frequency varies in a small range between 600 and 1,000 Hz, and is generally considered as quasi-constant in the automotive turbocharger operating speed range. Constant tone often occurs at engine speeds between 1,500 and 3,500 rpm in second to fifth gears with middle to high loads.

High-order harmonic noise often occurs in turbochargers using rolling element bearings (ball and roller bearings) where the constant tone fortunately does not happen. This noise type is caused by an inappropriate design of the oil damper clearance between the bearing outer race or cartridge and bearing housing [1]. The high-order harmonic noise has multiple harmonic frequency orders of 2, 3, 4, 5X, and above, as well as modulation sideband frequencies.

Wear noise mostly occurs in turbochargers using rolling element bearings (ball and roller bearings) if wear defects of balls, rollers, cage, inner, and outer races take place. The wear noise has different asynchronous frequencies that will be discussed in Sect. 4.5.

Crackling noise mostly takes place in wastegated turbochargers in which the waste gate (WG) vibrates about its pivot axis. This vibration generates the metallic crackling noise in various asynchronous frequencies between about 7 and 15 kHz in the WG open position. However, the crackling noise strongly reduces or diminishes when the WG is in the closed position due to the damped vibration amplitude at the waste gate seat located in the turbine housing.

The first four noise types are caused by aerodynamics in the compressor and turbine wheels. The unbalance whistle is induced by the rotor unbalance at high rotor speeds, and the constant tone is generated in the inner bearing hydrodynamic oil film. Both unbalance whistle and constant tone are therefore called rotordynamic noises. Rotordynamics engineers have studied both unbalanced whistle and constant tone and found that an appropriate two-plane rotor trim balancing at high balancing speeds reduces the unbalance whistle but not the constant tone; however, the constant tone could be released at an extremely large rotor unbalance.

In this book, the root causes of these noise types are studied; measures of reducing them are thoroughly discussed. Furthermore, efforts are also made to physically understand the noise behaviors and to reduce the undesirable noise generated in automotive turbochargers. Aerodynamic flows in compressor wheels are used to figure out the causes of the aerodynamic noises of the pulsation whistle, rotational, growling, and whining noises. Rotordynamics is applied to analyze the rotordynamic noises of the unbalance whistle, constant tone, crackling noise, high-order harmonic noise, and wear noise. And finally, some measures are discussed to improve the noise behavior (NVH) of automotive turbochargers in passenger vehicles.

Figure 2.2 shows the noise sources and response noises in a typical automotive turbocharger. The aerodynamic noise sources "1" of the pulsation, rotational, growling, and whining noises are transmitted from the turbocharger through the compressor housing to the air filter, air supply pipes, and air intercooler that are excited by the aerodynamic noise, leading to the response noises. The whining noise generally excites the intake-air supply components due to the flow reversal from the compressor outlet to the compressor inlet. On the contrary, the growling noise affects more the charge-air components, such as the charge-air duct and intercooler, as displayed in Fig. 2.2. The partial flow separation near the

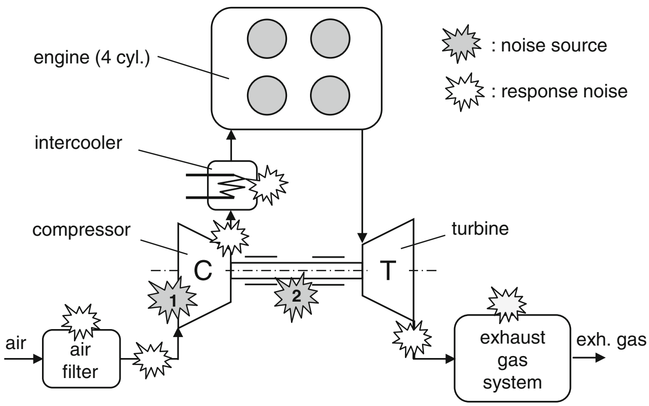

Fig. 2.2 Airborne noises of automotive turbochargers

compressor outlet is to blame for the growling noise propagating direction in the charge-air components; this will be discussed in detail in Sect. 4.1.

The rotordynamic noise sources “2” of the unbalance whistle, crackling noise, and constant tone in oil film bearings/high-order harmonic or wear noise in ball bearings are propagated through the bearing oil films/bearing balls and oil damper, and bearing center housing to the exhaust-gas system of the catalyzer, diesel particle filter (DPF), and muffler. The noise sources also excite the components neighboring the turbocharger, leading to the additional response noises. All induced noises are eventually transmitted through the car frame as airborne noises in the car cabin and environment. The audible airborne noise level depends on the vehicle types and operating engine speeds. Therefore, the delivery and limit acceleration unbalance levels must be determined for each car type; this will be discussed later in Sect. 4.2.

References

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