ActiveSilence for efficient Control of Exhaust Noise

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Introduction

Downsizing and downspeeding are important concepts for increasing the efficiency of combustion engines. However, these concepts will inevitably lead to higher noise levels in a lower frequency range where they are more difficult to handle with conventional muffler design. Moreover, the increasing number of vehicle models and platform derivatives leads to a huge variety of exhaust systems even within a single OEM platform. This causes significant effort in development, tooling, manufacturing, part handling, and logistics. In order to overcome this challenge, the Eberspächer ActiveSilence® technology based on Active Noise Cancellation (ANC) aims at resolving the conflicting objectives by using active components in the exhaust system. In this publication the advantages regarding package space, weight, acoustical performance and transient behavior are demonstrated on the basis of a specific case study.

ActiveSilence Application

Generally, the muffler volume requirements rise directly with engine power and lower backpressure targets. In passenger cars, the overall muffler volume typically is distributed over several mufflers positioned in the underbody of the vehicle. The present case study is based on an AUDI A5 demonstrator vehicle (2.0L 4-cylinder gasoline engine with 155 kW). The layout of the serial production exhaust system consists of one front muffler, one center muffler and two separate rear mufflers associated with two tailpipes [1]. The rather complex muffler set-up is needed to achieve package constraints, backpressure requirements, and premium sound quality targets at the same time.

The application of the ANC technology in exhaust systems of internal combustion engines (ICE) offers the possibility to replace passive mufflers, and therefore to reduce the total muffler volume. Overall, it has been found that the potential main advantages of the technology are:

- high efficiency in reducing dominant engine orders, leading to smaller mufflers,
- simplified development procedures and reduced development costs and time,
- uniform muffler construction leading to more carry-over-parts and avoiding costly tooling,
- limitation of acoustic muffler variants due to slightly different packaging, sound and tailpipe trim variants,
- low backpressure resulting in higher engine performance,
- software control of engine orders allowing an adaptive sound design and easy sound customization,
- reduced number of additional mechanical parts e.g. heat shields, exhaust and body side hangers, isolators,
- support of light weight efforts to improve driving dynamics and fuel economy.

In recent years, the active components (actuators, microphones, electronic hardware and software) were consistently improved and their durability professionally validated [2]. It has been found that the benefits of the ANC technology can compensate for the extra cost associated with the active components. The set-up of the active exhaust system of the present case study is depicted in Figure 1.

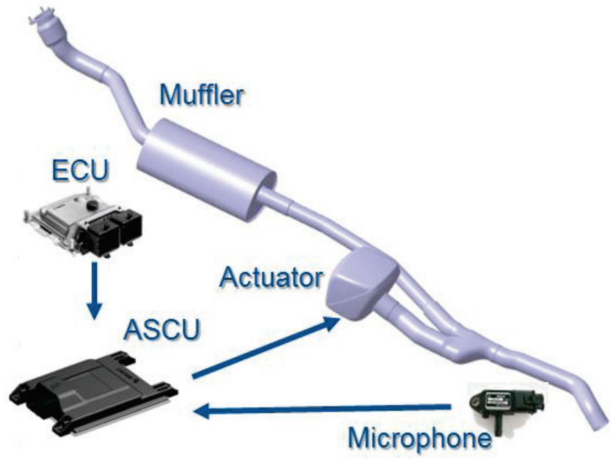

Figure 1: Set-up of an ActiveSilence exhaust system.

Here, the rear and center mufflers of the serial production system are replaced by an actuator which receives its input from an ActiveSilence Control Unit (ASCU). A single muffler in front position reduces flow noise and engine orders (EO) to a level, which the actuator can cancel out. The relevant exhaust data of the active system is compared to the serial production exhaust in Table 1. Evidently, for the active system, the total muffler volume is reduced by 27 L and a marked reduction in weight by 8 kg is achieved.

Table 1: Exhaust data of the cold-ends of a 2.0 L 4-cylinder gasoline turbo-charged engine

	Production System (dual exhaust line)	**Active System** (single exhaust line)
Total muffler vol. (including actuator)	50 L	23 L
Backpressure	160 mbar	160 mbar
Overall weight	27 kg	19 kg

Acoustic Measurement Results

Acoustic measurements were performed on a roller-dynamometer test bench. To allow a fair comparison of the noise radiation from the dual tailpipes of the production system with that of the active single exhaust, the microphone was located at a distance of 1.0 m centered behind the car and at a height of 1.5 m.

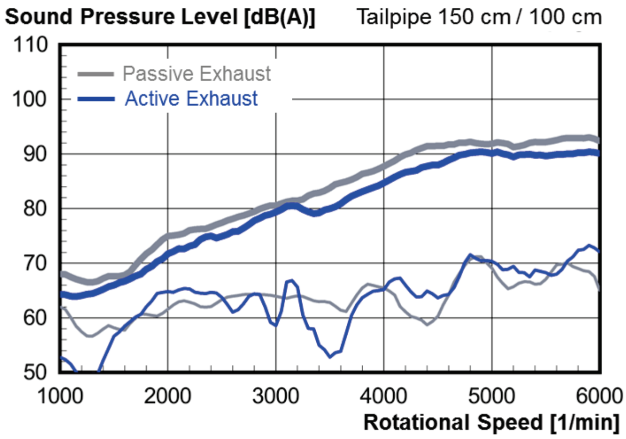

Figure 2: Measured overall and 2nd EO SPL at the tailpipe of the 4-cylinder gasoline engine at full load (bold lines – OVL; thin lines – 2nd EO).

In Figure 2, the acoustic results for full load acceleration are shown for the overall sound pressure level (bold line) and the 2nd EO (thin line), which is the most important engine order. Within the range of investigated engine speeds, the A-weighted overall SPL of the ANC system is up to 3 dB below the production system SPL. This fact is due to good cancellation of all relevant EO, careful CFD-design, an increased pipe diameter, and consequently lower Mach numbers in the pipe resulting in low flow noise. For the 2nd EO the ANC system is superior mainly at low engine speeds up to about 1.500 rpm. Above this engine speed the 2nd EO SPL of the active system is similar with the production system but also less relevant for the overall SPL.

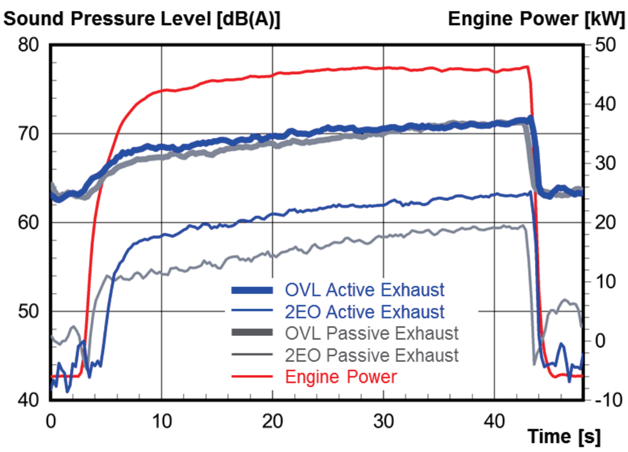

Figure 3: Measured overall and 2nd EO SPL at the tailpipe of the 4-cylinder gasoline engine and varying load (left axis: bold lines – OVL; thin lines – 2nd EO; right axis: red line – engine power at ca. 1.500 rpm).

To further illustrate the acoustic performances, a test of the transient behavior was set-up on the roller-dynamometer. For this reason, the engine speed was held constant at 1,500 rpm, whereas the engine load condition was changed by first rapidly pushing and later releasing the gas pedal. Figure 3 shows the OVL and 2nd EO SPL together with the instantaneous engine load for the conditions no load (0-1.5 s), full load (1.5-44 s) and no load (44-48 s). Note that, here, for the active exhaust system the power dedicated to the 2nd EO was reduced via software parameters. Nevertheless, the active exhaust system shows no overshoot in the transient regimes. The rise of the OVL and 2nd EO SPL during the high engine load phase for both exhaust systems is due to the slowly increasing engine power and exhaust temperature, both leading to increasing noise excitation.

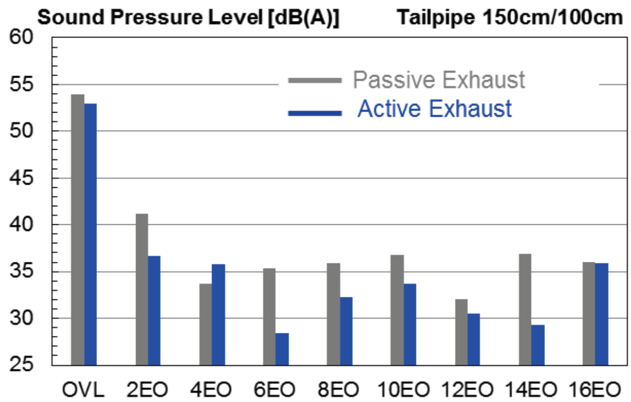

Figure 4: Measured SPL at ca. 750 rpm in idle condition at the tailpipe of the 4-cylinder gasoline engine (grey columns - production system; blue columns – ANC system).

Another important vehicle and engine condition for an evaluation of the acoustic performance is the idle condition. Thus, measurements were carried out with both exhaust systems in a warmed-up state. From the results shown in Figure 4 it is evident, that the overall SPL is slightly lower for the ANC system, but EO SPL differ considerably. In the applied ANC software parameters, the 4th to the 14th EO are cancelled. While at the 6th and 14th EO the ANC system performs well, the active cancellation of 4th EO should be improved and 16th EO should be included in the cancellation control to improve the performance in future projects.

Conclusion

In the present paper, a case study is presented, where a serial exhaust system is compared with an active exhaust system in terms of package space, overall weight and acoustic performance. The benefits of the ANC technology have been demonstrated and they are found to compensate more and more the efforts which are associated with the additional components (e.g. loudspeaker, microphone, and electronics). The current status of the ANC technology and the gathered detailed application experience allows easy adaptation to different customer requirements and package situations.

References

[1] Krüger, J.; Pommerer, M.; Frei, T.: Progress on Active Exhaust Silencers for Gasoline Engines. Proceedings to AIA-DAGA 2013 Merano.

[2] Krüger, J.; Koch, V.; Buganza, F.: The effects of future noise limit values on the design of exhaust systems. ATZ – Automobiltechnische Zeitschrift 09 (2016), Vol. 118, p. 48-51.