Active Exhaust Silencers for Internal Combustion Engines

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Introduction

In the past years, Eberspaecher has developed active exhaust silencers for several passenger vehicles with different engines on a prototype level. In general, a substantial reduction of the exhaust noise is regularly achieved in a frequency range of ~40 – 400 Hz covering all relevant engine orders. Further progress was made in the development of the durability and industrialization of the necessary components of the system.

In exhaust system development the main design conflicts are noise reduction, silencer volume/weight and backpressure. Furthermore, the global cost target and the often challenging development times pose a limitation to the engineering optimum. The Active Noise Technology in principle has the potential to address theses basic design conflicts and its advantages can be summed up as follows:

- high efficiency in reducing dominating engine orders, leading to smaller mufflers,
- low backpressure resulting in higher engine performance and/or to some extent lower fuel consumption,
- software control of engine orders allowing an adaptive sound design and easy sound customization,
- uniform muffler construction leading to more carry-over-parts, simplified development procedures and reduced development time.

To apply this technology to automotive exhaust systems Eberspächer has developed a system design, where the rear silencer is replaced by an Aktor with integrated loudspeaker which receives its input from a controller and amplifier hardware. In this electronic hardware, the software algorithm calculates the anti-noise signal controlled by the ECU (Engine Control Unit) and a signal from an error microphone. An overview of the set-up is given in Figure 1.

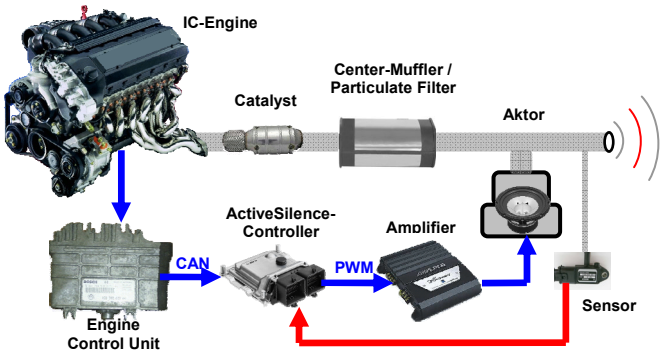

Figure 1: General set-up of the ActiveSilence®-System

Case study: 4-cylinder gasoline-engine

In a first case study, an active exhaust system was developed for a premium limousine with a 2.0 L four cylinder gasoline turbo charged engine with direct injection (147 kW; 280 Nm) with dual exhaust system. See relevant data below:

Volume of:	Production System	Active System
Inter silencer	12.4 L	12.4 + 3.0 = 15.4 L
Rear silencer	2 x 13.5 = 27 L	2 x 5.0 = 10 L

In the active system the two rear silencers were replaced by two Aktors with a volume of ~5 L each. In addition, a small pre-silencer of 3 L was integrated resulting in an exhaust system of roughly the same weight and backpressure. Overall, a silencer volume reduction of ~14 L equivalent to 36 % was realised with the active exhaust silencers. The acoustic results are shown in Figure 2 and 3 respectively measured on a roller test bench at WOT (Wide Open Throttle = full load) and at a distance of 0.5 m and under an angle of 45 ° relative to the orifice exit.

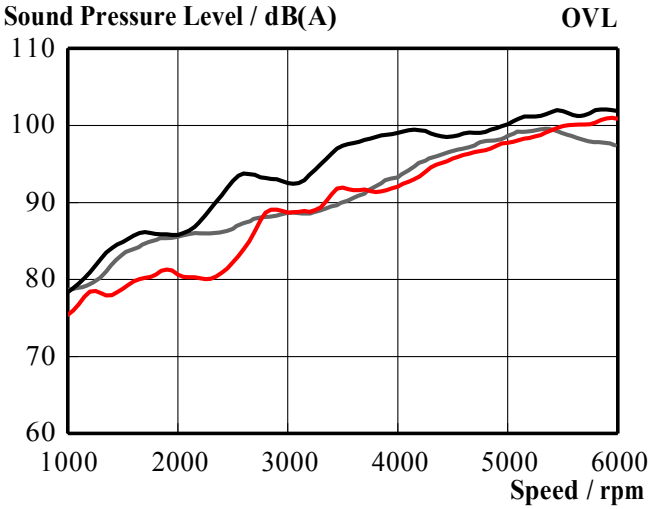

Figure 2: Overall sound pressure level at the tailpipe of the 4-cylinder gasoline engine (grey - production system, black - ANC off, red - ANC on)

When the ANC-system is switched-off, the overall level is ~5 dB(A) higher than the production system. However, with the ANC turned on, a significant reduction is measured ranging from 2 to 8 dB(A); thereby achieving an improvement over the production system in almost the entire speed range. Figure 3 shows the 2nd engine order of the same measurement where the effect of the ANC-system can be seen more clearly. It starts at about 1200 rpm (40 Hz) with 10 to 20 dB reduction. Since other relevant engine orders were also substantially reduced actively, the influence of the exhaust noise on the interior noise level was effectively removed. It can be demonstrated that the acoustic comfort inside this particular demonstration vehicle was superior to the production status

and reached a level of refinement typical for luxury limousines only.

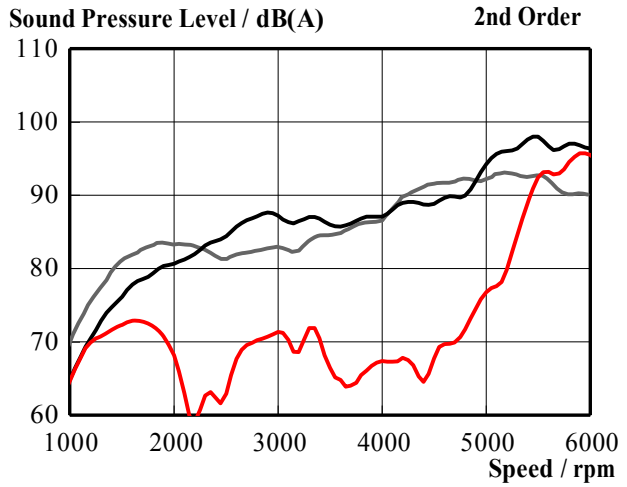

Figure 3: 2nd engine order sound pressure level at the tailpipe of the 4-cylinder gasoline engine (grey - production system, black - ANC off, red - ANC on)

Case study: 6-cylinder diesel-engine

In a second case study, an active exhaust system was developed for another premium limousine with a 3.0 L six cylinder diesel engine with turbo charger (170 kW; 450 Nm) and the following relevant data of the dual exhaust system:

Volume of:	Production System	Active System
Rear silencer	2 x 13.5 = 27 L	2 x 5.0 = 10 L

The production exhaust system included a particulate filter but no inter silencer. In the active system, the two rear silencers were replaced by two Aktors with a volume of 5 L each. The overall volume reduction is thus ~17 L which is equivalent to 63 %. Furthermore, the backpressure of the production exhaust could be lowered by ~150 mbar resulting in an increased engine power of at least 1-2 %. Comparing the system weights, the active system including ANC-controller and amplifier are roughly on the same as the production system.

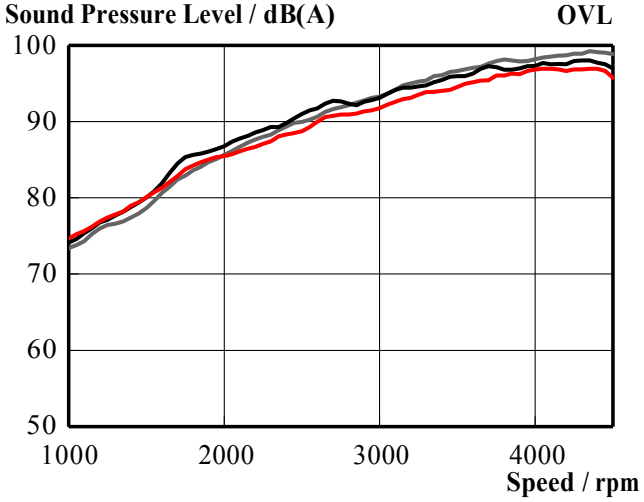

Figure 4: Overall sound pressure level at the tailpipe of the 6-cylinder diesel engine (same colours as above)

The acoustic results are shown in Figure 4 and 5 respectively are measured the same way as the first case study. The A-weighted overall level is dominated rather by flow noise rather than by engine orders like typical diesel engines. The overall level changes by few dB(A) with the ANC-system switched on or off which is close to the production system. Nevertheless, figure 5 shows in more detail the 3rd engine order of the same measurement; the effect of the ANC-system is clearly visible. In fact, the active noise reduction reaches about 10 to 20 dB in the entire speed range. Compared to the production system the actively controlled 3rd engine order remains on a similar low level thereby neither affecting the overall tailpipe nor the interior noise.

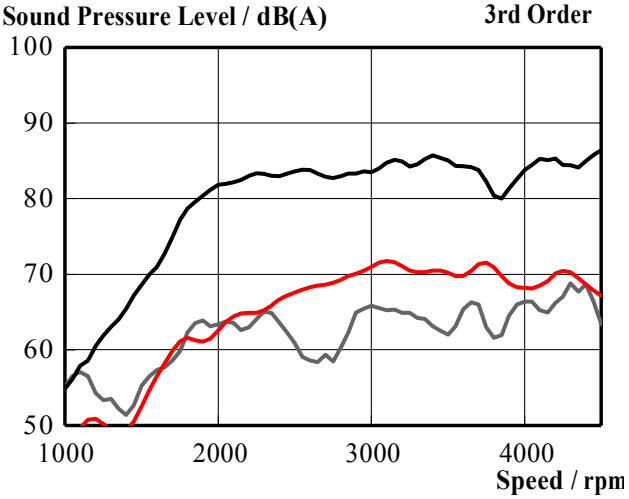

Figure 5: 3rd engine order sound pressure level at the tailpipe of the 6-cylinder diesel engine (same colours as above)

Conclusion

The feasibility of active silencers under the harsh conditions of automotive exhaust systems has been demonstrated. Several functional advantages were proven such as the acoustic performance, silencer volume and backpressure reduction. The durability of the ANC system has been improved; further emphasis in future development work will be directed towards the overall system cost. This technology can be introduced in automotive mass production if the additional cost for loudspeaker, controller hardware, and software can be compensated by higher functional performance or added customer value (e.g. improved sound design).

References

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