Absorption mufflers in exhaust systems

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Abstract

Absorption mufflers or combined absorption/reflection mufflers are an almost indispensable element of modern exhaust systems. A fundamental knowledge of the mechanism of action of the absorption material is just as important as a calculation method for designing the mufflers in order to ensure that they are optimally used. This paper presents the results of a detailed study of absorption mufflers and compares these with the predictions of WAVE.

It is found that the absorption material is not only effective in the high frequency range, as was already known, but also has a distinct effect on the exhaust noise in the lower frequency range. This effect can easily be calculated with the new absorption module for WAVE.

1. Introduction

Exhaust noise can be attenuated in several ways. A distinction is generally made between active and passive attenuation, although purely active mufflers are not yet ready for production in series. For this reason, modern exhaust systems consist of one or more passive reflection or absorption mufflers. Reflection mufflers attenuate the sound by reflection and interference; absorption mufflers dissipate the acoustic energy into heat energy through the use of porous materials as mineral fibre.

The use of these two muffler types depends on the objectives with regard to the noise level and characteristic sound of the exhaust system. Absorption mufflers are generally expected to ensure good attenuation in the middle to high frequency range (> 500 Hz) with little backpressure.

However, the effects on the lower frequency range (firing frequency and its harmonics) have not yet been studied, although they dominate the exhaust noise. For this reason, this paper will not only summarize the attenuation of absorption mufflers, but will also investigate the change in the first engine orders when using absorption material. Measurements using both an engine as well a loudspeaker for exciting the exhaust system will be presented and discussed here.
WAVE has recently been expanded to include absorption material (WAVE release 3.5). Calculation of absorption is based on the flow resistance of the absorption material and on the heat transfer between gas and absorption material. A detailed description of the calculation method can be found in [1]. The results generated by that calculation model are validated in this paper against measurements.

2. Investigation of a simple exhaust system

A simple concentric resonator with perforated inner pipe (Fig. 1) was selected for the basic investigation. Rock-wool in various bulk densities (packing densities) was used as the absorption material. (The effect due to the size of the muffler, the perforation density and different absorption materials was also investigated, but will not be presented here for lack of space.)

![Absorption muffler SD (perforation density of inner tube: 0.3)](image)

Fig. 1: Absorption muffler SD (perforation density of inner tube: 0.3)

2.1 Loudspeaker excitation of the absorption muffler

The purely acoustic response after excitation by loudspeaker at room temperature and without gas flow was characterized with transmission loss measurements and compared to the WAVE transmission loss calculations of the muffler from Fig. 1.
In Fig. 2 can be seen that the absorption material has a distinct effect on the attenuation of sound. Even with very low packing densities the pass bands, showing up for the empty muffler, can be attenuated very effectively. The attenuation increases with increasing packing density up to 120 kg/m³. Below 250 Hz no attenuation is visible for the transmission loss measurements.

The agreement between measurements and WAVE calculations is good for all packing densities and frequencies below 500 Hz. At higher frequencies and packing densities higher than 80 kg/m³ the attenuation predicted by WAVE is too low. The reason for that behaviour is still under investigation.

2.2 Engine excitation of the absorption muffler

Measurements under realistic conditions (high sound level, high gas speed and temperature) were carried out with engine excitation in an anechoic chamber. For this purpose, the muffler from Fig. 1 was connected to a 6-cylinder engine with catalytic
converter (standard series) as shown in Fig. 3. The exhaust noise was measured in the near field under full-load acceleration.

![Test set-up, exhaust system 1 in an anechoic chamber](image)

**Fig. 3:** Test set-up, exhaust system 1 in an anechoic chamber

As can be seen in Fig. 4 a) the unweighted overall level is dominated by the firing frequency (3rd engine order) and its first harmonic (6th order).

![Overall noise with the dominant engine orders for exhaust system 1 with empty muffler (left) and packed muffler (right).](image)

**Fig. 4:** Overall noise with the dominant engine orders for exhaust system 1 with empty muffler (left) and packed muffler (right).
Fig. 4 b) shows that the 3rd and 6th engine orders still account for a considerable proportion of the A-weighted overall noise (i.e. despite lowering the low frequencies by up to 30 dB). The 9th and 12th order also play a part in the empty muffler, as these pass through a pipe resonance at 560 Hz (9th order at 3800 rpm and 12th order at 2800 rpm). The packed muffler is 2-6 dB quieter than the empty muffler over the entire speed range (see Fig. 4). This lower level is essentially due to changes in the 3rd to 12th order when using rock-wool. The changes have been plotted in Fig. 5 as differences in level between the empty muffler and the muffler packed with 160 g/l. Negative/positive values reflect an improvement/deterioration in the exhaust level as a result of the rock-wool.

Fig. 5: Difference in order level for exhaust system 1 with empty and packed muffler (160 kg/m³ rock-wool). Both measured values and calculated values have been plotted.

The exhaust system shown in Fig. 3 was then modelled with KADOS (the intake and exhaust preprocessor for WAVE [2,3]) and calculated with WAVE. Both cases (empty mufflers and packed mufflers) were calculated and the difference plotted in Fig. 5 (red curve). The results correlate well with those obtained by measurement. The accuracy of the WAVE prediction declines at frequencies above 800 Hz due to the discretization length of 30 mm in the WAVE model of the exhaust system (refer also to references...
This is evident in the larger discrepancy between model and measurement for the 12th order in the higher speed range. The change in the 3rd order when using absorption material is remarkable. The level improves distinctly in the lower speed range (1000 – 1800 rpm) and increases in the range 1800 – 6000 rpm. This is an effect which is explained in more detail in Ref. 4. In summary it is due to changes in the resonance characteristics of exhaust systems with absorption mufflers as compared to exhaust systems with reflection mufflers of the same design. The absorption material leads to a displacement in the resonance frequency of the muffler chamber which acts as spring and of its inlet pipe which acts as mass. This resonance is often located in the range of the firing frequency – as was also the case with the exhaust systems investigated here – and therefore has a distinct effect on the overall level.

3. Investigation of a standard system

The above described effect is found not only in simple exhaust systems, but also in the typical standard exhaust systems used in passenger cars. As an example a standard exhaust system for a 6-cylinder engine was investigated (Fig. 6). This exhaust system has a middle muffler completely packed with rock-wool and a partially packed rear muffler. Measurements on the standard system were complemented by measurements on the same mufflers without packing.

Fig. 6: Exhaust system 2 (standard exhaust system for a 6-cylinder SI engine)

The exhaust system was also modelled with KADOS and with WAVE for both empty and packed mufflers. The results are presented in Fig. 7. The measured values correlate well with the calculated values.
Both measured values and calculated values have been plotted.

As in the case of the simple exhaust system, the 3rd engine order is once again reduced, thus reducing the overall noise in the lower speed range when using rock-wool. The same increase in the 3rd order is also found at the higher speeds (2300 – 6000 rpm in this case). Attenuation of the higher frequencies has no effect on the overall level, but has a distinct effect on subjective perception of the exhaust noise.

4. Summary

The effect of absorption material on the attenuation characteristics of mufflers was investigated. Measurements carried out with an engine as noise source have shown that absorption mufflers attenuate the middle to high frequencies quite effectively, particularly at the pipe resonances in the lower speed range. Compared with reflection mufflers, the overall level is more strongly dominated by the first engine orders, thus distinctly affecting the subjective perception of the exhaust noise. At the same time, however, the use of absorption material also has a distinct effect on the low frequency range and on the engine orders.
WAVE was hitherto used only for modelling reflection mufflers. With the new absorption module, WAVE can now also predict changes in the first engine orders, as well as changes in pipe resonances in the middle frequency range (up to 600 - 800 Hz) when using absorption material. At the same time it can also provide information on the backpressure of an exhaust system and its effect on performance and torque. A comprehensive calculation method is therefore available for designing exhaust systems with all the standard types of muffler.


