Acoustic Behaviour of an Automotive Radiator

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Introduction

Modern engine compartments become more and more encapsulated, even the opening to the underneath car cavity gets closed for aerodynamic and acoustic reasons. But as long as combustion engines need fresh air to cool the coolant, an opening for the heat-exchanging radiator will still remain. Of course, through that opening a major part of noise is also emitted. That is why a detailed acoustic analysis of a finned radiator – as the only element between engine and opening – becomes motivated.

The radiator is approximated as a porous absorber, comparable to the model proposed by Lord Rayleigh. With this theoretical model, essential acoustic characteristics of the radiator are computable. How strong the acoustic influence of the radiator is and how far results gained from the theoretical model cover reality, is shown by comparing them with those of experiments.

Modelling the Radiator

The model of a porous absorber – provided by Lord Rayleigh – assembles air-filled volumes of pores to parallel ducts. As shown in Figure 1, significant similarities between model and the radiator exist.

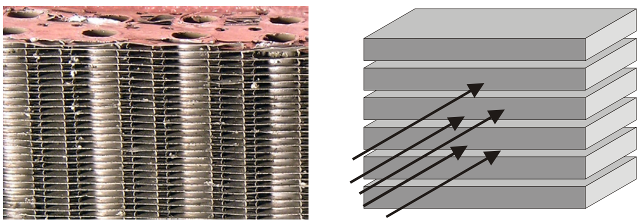

Figure 1: Comparison of the radiator with the model of a porous absorber by Lord Rayleigh.

The major effect of a porous absorber is the transformation of sound energy into heat, which results from friction caused by air flowing through the small ducts. The absorption reaches high values when wave components with high velocity are propagated inside the absorber.

Material Characteristics of a Porous Absorber

As shown in textbooks [1] or [2], absorption of an absorbing material is mainly influenced by three material characteristics: its porosity σ (ratio of air-filled to total volume), its specific flow resistance Ξ and its structure factor κ (ratio of total air volume to permeable volume).

Equivalent Network of the Radiator

For the measurements, the radiator will be mounted at the end of a Kundt's tube, which will be left open to simulate a practice-oriented built-in situation. Therefore, the equivalent network has the form of a series connection, which consists of the radiator's input impedance Z_R and the impedance of a spherical wave Z_S that exists at the end of the tube acting like monopole source. The measurable total impedance Z_{total} is then calculated by

$$Z_{total} = Z_R + Z_S \tag{1}$$

Z_S is only influenced by the diameter r_{tube} of the Kundt's tube, whereas the material characteristics of the radiator are mainly responsible for its input impedance Z_R:

$$Z_R = d\Xi + j\omega m'' = d\Xi + j\omega \frac{\rho_0 \cdot d \cdot \sigma}{\kappa} \tag{2}$$

$$Z_S = \rho_0 c_0 \frac{jk_0 r_{tube}/2}{1 + jk_0 r_{tube}/2} \tag{3}$$

with $\omega = 2\pi f$, m'' = surface-related mass,
ρ_0 = density of air, c_0 = sound speed, $k_0 = \omega / c_0$

Also the absorption coefficient α can be determined from the Kundt's tube measurement:

$$\alpha = 1 - |\underline{\Gamma}|^2 = \frac{4 \cdot \rho_0 c_0 \cdot \mathrm{Re}(Z_{total})}{[\rho_0 c_0 + \mathrm{Re}(Z_{total})]^2 + [\mathrm{Im}(Z_{total})]^2} \tag{4}$$

($\underline{\Gamma}$ is the reflection factor, gained from Kundt's tube measurement rules.)

Kundt's tube measurements have to be done in discrete frequency steps, that can be seen as the main disadvantage of this method. For that reason, the radiator's input impedance was also measured with the 2-microphone random-excitation technique [3], which enables measurements over a continuous frequency range, only restricted by the physical dimensions of the used measurement duct. With an additional third microphone mounted at the other side of the sample, it is also possible to determine the transmission loss $R_{I,plane}$.

For both methods, the normal incidence is adressed. Hence, obtained results may not be transferable to a real built-in situation at all, where the radiator is mounted in a wave field with a more random incidence.

In addition to these measurements, the transmission loss $R_{I,diffuse}$ was measured in accordance with EN ISO 15186-1 [4], realized in a window test stand, where now a stationary diffuse sound field was provided.

Experimental Verification

Measuring the Material Characteristics

The structure factor for the radiator was set to κ = 1.

By measuring the displaced water in a water bowl, the porosity of the radiator was determined to σ = 0,78.

The specific flow resistance Ξ was obtained by measuring the pressure before and behind the radiator installed in duct, at constant volume flows. A value of Ξ = 0,462 Rayl/cm was determined, which is a very small value in comparison to other porous absorber materials. Although a frequency-dependent measurement of Ξ was not possible, the present value should be a good assumption, at least for low frequencies.

Measuring the Acoustic Characteristics

In the following graphs, the results from the measurements of the acoustic characteristics (solid blue line) are compared to those from theory (dash-dotted red line).

For the measurements with the Kundt's tube, good conformances with theory are shown, at least for frequencies up to 500 Hz. There above, there are possibly additional frequency-dependent influences.

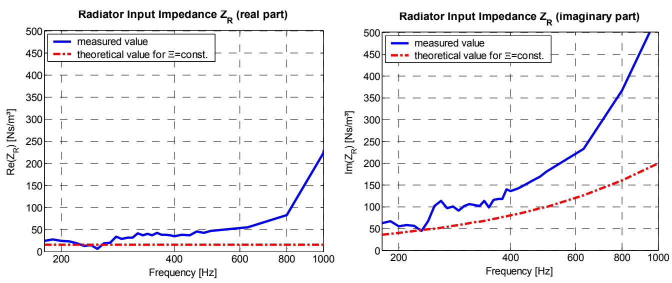

Figure 2: Real and imaginary part of the input impedance Z_R, measured in the Kundt's tube.

For the measurements with the 2-microphone random-excitation technique, the radiator sample was mounted in a duct, just in front of a rigid wall.

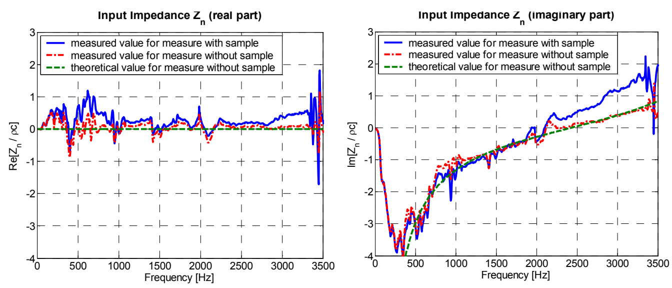

Figure 3: Real and imaginary part of the input impedance measured with the 2-microphone random-excitation technique.

In figure 3, the solid blue line shows the measurment results. The dash-dotted red line represents a measure without the sample, which confirms the theoretical value, graphed by the dashed green line.

In comparison to the Kundt's tube measurements, the measurements with the 2-microphone random-excitation method show similar tendencies in general, but demonstrate also the limited acoustic influence of the radiator. Only at higher frequencies (*f* > 2500 Hz), a significant influence of the radiator is observed.

Finally, the transmission loss R_I and the absorption coefficient α were measured.

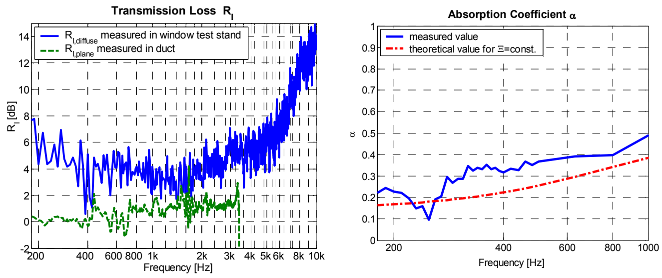

Figure 4: left) Transmission loss R_I, measured in diffuse and plane wave field. right) Absorption coefficient α

Because of the small acoustic influence of the radiator, measurements have to be done very carefully, which makes them susceptible to errors. This may be a reason for the deviations of both measurement methods.

Concluding Remarks

The general acoustic behaviour of a finned radiator is addressed, a good agreement between theoretically calculated and measured values is obtained, at least for the frequency range 180 to 500 Hz.

In comparison with radiators of other manufactures, the chosen one (used in a Nissan Micra) is very fine-structured, which would promote the absorption effect. Nevertheless, the acoustic influence of the radiator is more or less negligible. Due to the small flow resistance and the small depth, the radiator constitutes no obstacle for the sound waves. The absorption effect becomes strong at high frequencies, when wave lengths are short enough (λ < *d*). Thus, the radiator represents an acoustic opening in the engine compartment.

In order to pursue the goal of low noise emission of cars, a constructive modification of a radiator would be desirable, which combines both, good air flow and high sound absorption. This is, however, a constructive contradiction, at least for the state-of-the-art radiators.

References

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