

Compact High-Pressure Intake Silencer with Multilayer Porous Material

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ABSTRACT

Intake noise has become one of the main concerns in the design of highly-supercharged downsized engines, which are expected to play a significant role in the upcoming years. Apart from the low frequencies associated with engine breathing, in these engines other frequency bands are also relevant which are related to the turbocharger operation, and which may radiate from the high-pressure side from the compressor outlet to the charge air cooler. Medium frequencies may be controlled with the use of different typologies of resonators, but these are not so effective for relatively high frequencies. In this paper, the potential of the use of multi-layer porous materials to control those high frequencies is explored. The material sheets are located in the side chamber of an otherwise conventional resonator, thus providing a compact, lightweight and convenient arrangement. Several configurations have been tested in an impulse rig, without and with a superimposed mean flow, and the results have been analyzed with the help of a simple linear finite volume model accounting for the material. Then, the model has been used to explore different combinations of geometry and material properties, with the purpose of defining design guidelines for a proper choice of the device size and the material used, that may allow fulfilling the targeted value.

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INTRODUCTION

One of the current trends in the development of low emission vehicles [1] is the reduction in the car weight, so that it is becoming more and more difficult to achieve a high insulation level of the passenger compartment against the engine noise. In the case of turbocharged engines, particular problems arise [2]: on one hand, the influence on orifice noise of the waves generated by the sequence of opening and closing valves has been reduced dramatically. Indeed, both the turbo-compressor itself [3,4] and the charge air cooler [5] introduce significant damping for those low frequencies issues. On the other hand, new sources appear in the mid and high frequency range [6].

Many solutions have been proposed in order to improve quietness for mid- frequency range noise in an efficient way while avoiding any increase in pressure drop. In these solutions, with the purpose of controlling noise as close as possible to the source it is usual to implement some reactive silencers at the inlet and/or at the outlet of turbo-compressor, including different resonator arrangements [7, 8], interference silencers [9] and, more recently, micro-perforated materials backed by a locally reacting chamber [10]. However, in the case of supercharger or newest high pressure turbocharger noise significant sources appear at higher frequencies, which may require

treatment for frequencies that can reach 10 kHz with attenuations in the order of 15dB. In those specific cases, reactive silencers are useless because the waves are not propagating only as plane waves anymore and also because the required resonating volumes would be too small to be efficiently excited. The purpose of this paper is to propose and evaluate a new kind of silencer that might be able to address such high frequency issues with more complex propagating wave shape above the cross mode of the duct. By changing the mechanism of attenuation from reactive to resistive, this new solution could be actually efficient for the higher frequency range without the need for a heavy tuning effort. A picture of the proposed device is shown in Fig.1. The dissipative effect is attained through the use of an innovative multi-layer porous material. Since the packaging volume close to the turbocharger outlet is constrained, the same outer shell of a mass production part (about 3 mm thick) has been used for the tested device. The overall diameter is around 80 mm with a length of 80 mm and the inner diameter is about 35 mm. The material is supplied in sheets with thicknesses from 0.5 to 3 mm, and the cavity is filled by folding the material around, so that the resulting number of layers depends on the material used. Because of its nature, the material cannot be carried away with the air flow and thus there is no need of any additional grid which could affect the acoustic performance.

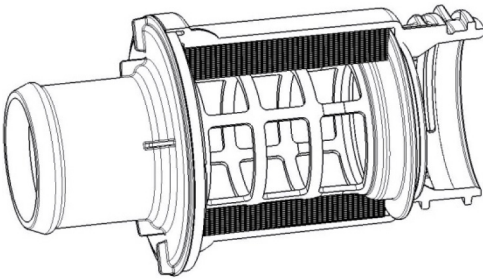


Figure 1. Scheme of the proposed device.

The paper is organized as follows: first, the experimental set-up is described and the experimental results on a first set of prototypes are discussed. Then, the models considered in the subsequent analysis are briefly described. These models are then used to explore different trends related with the geometry of the device and the properties required from the material. Finally, conclusions are drawn that may provide guidelines for the proper choice of the different design parameters.

EXPERIMENTAL SET-UP

The experimental set-up used, together with an illustration of the measurement principle, is depicted in Fig. 2. Two main parts can be distinguished: the pulse generation system and the ducting for pulse propagation and measurement [11], and the mean flow supply. These two systems are briefly described in the following.

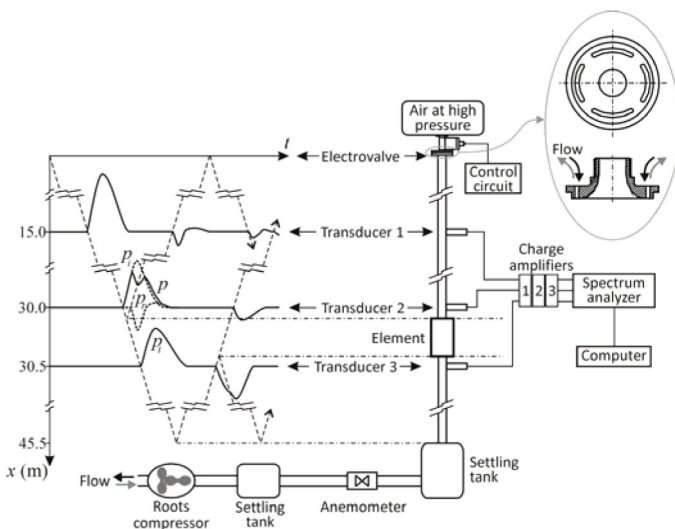


Figure 2. Scheme of the experimental set-up.

Regarding the pulse generation and propagation system, the element is excited by means of a pressure pulse generated by using an electrovalve that controls the discharge from a high pressure tank. The amplitude and the duration of the pulse can be controlled by modifying the tank pressure and the opening time of the valve in such a way that a substantially flat spectrum is achieved, thus ensuring a proper excitation. As the generated pulse propagates down the pipe (wave paths are indicated in Fig. 2 by dashed lines) instantaneous pressure is measured with piezoelectric transducers at three different

points: midway between the electro-valve and the element (transducer 1), just upstream of the element (transducer 2), and downstream of the element (transducer 3). The duct lengths between the valve and the first transducer and between the third transducer and the last reflecting boundary were chosen so as to enable the isolation of the pressure pulses in the time domain at transducers 1 and 3, and thus the pressure recorded by transducer 3 gives directly the pulse transmitted by the element.

The required steady air mass flow is supplied by a roots compressor driven by an electrical motor connected to the voltage source through a frequency converter, allowing the fine control of the mass flow through the element studied. A 30 liter expansion chamber is located downstream of the compressor in order to reduce the pressure fluctuations generated by the blower. The stabilized mass flow is conveyed through a 110 mm diameter pipe up to a hot film anemometer, where the mass flow rate is measured. A 200 liter volume is placed at six diameters downstream of the anemometer in order to ensure stagnation conditions downstream of the flow meter. The volume outlet provides the last reflecting boundary to the pulse propagation within the ducting. The detail in Fig. 2 shows the four ports drilled in the flange connecting the electro-valve to the propagation duct, which were designed considering the pressure drop generated, which should not be excessive for the blower, and the room available for different diameters of the propagation duct.

In order to assess the quality and representativeness of the measurements, in Fig. 3 an example of the spectrum of the incident pulse, the spectrum of the transmitted pulse and also the spectrum of the background noise signal, referred to as "threshold" in the figure, are shown. It is apparent that the incident spectrum is sufficiently flat so as to excite the device at all the frequencies. The only feature that can be observed in both the incident and the transmitted spectra is a sort of ripple close to the cut-on frequency of the first transverse mode, between 5000 and 5500 Hz, which appears more clearly in the transmitted spectrum. The impact of this issue on the results will be commented in the next section. Additionally, it can be observed that the background noise is acceptably low, as it only overlaps with the transmitted signal around the frequencies just commented.

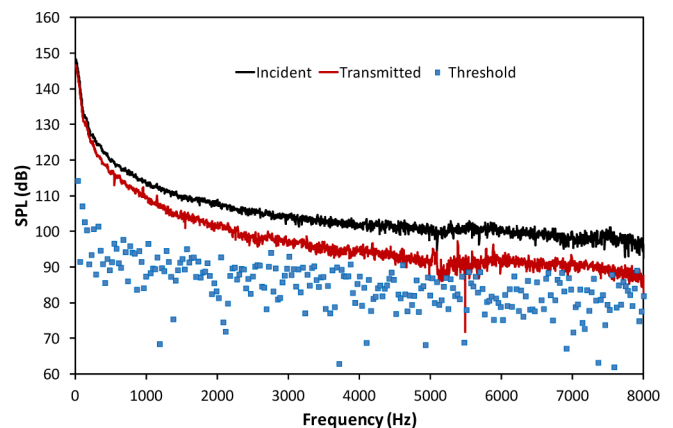


Figure 3. Comparison of incident and transmitted spectra with the threshold of the transducer.

EXPERIMENTAL RESULTS

Four prototypes equipped with different porous materials were built and tested without and with a superimposed mean flow. An overall view of the results is given in Fig. 4, where the transmission loss of the four prototypes is plotted together with that of an empty device without any porous material. The expected features associated with the dissipative character of the attenuation mechanism (suppression of reactive features associated with the naked geometry, both pass-bands and attenuation spikes) are clearly observed for all the materials except that denoted as "material 2", in which the attenuation is consistently lower than that provided by the device without any porous material.

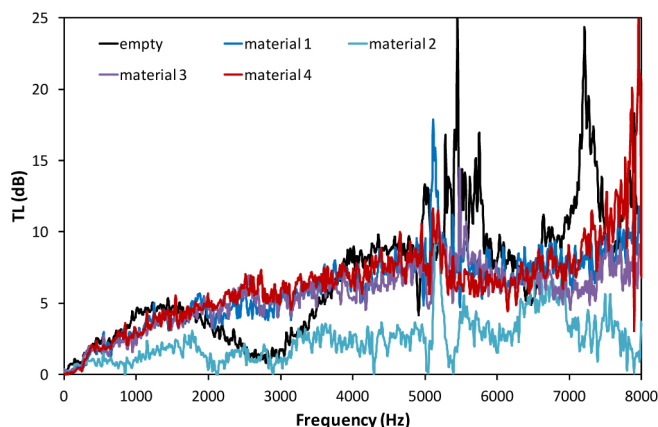


Figure 4. Transmission loss of the device: without material and with the four materials considered.

Apart from this, it can also be observed that, in all the cases, a very narrow spike appears around the frequency mentioned in the previous section. This strongly suggests that the measurements are contaminated locally, in this very narrow frequency band, by the excitation of the transverse mode of the propagating duct. This might be also supported by the fact that one should expect a more efficient excitation of this mode downstream of the device, due to the unavoidable non-symmetries in the actual mounting. Therefore, this particular frequency band will be obviated in all the subsequent analyses, all the more as it does not appear to affect the acoustic response at all the frequencies above and below considered in the study.

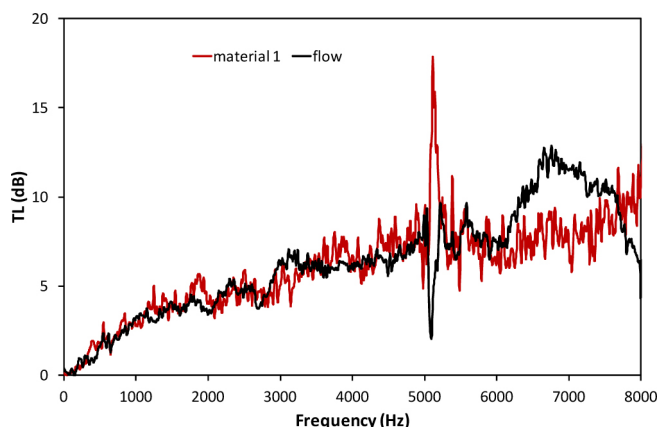


Figure 5. Effect of the flow on the transmission loss: material 1.

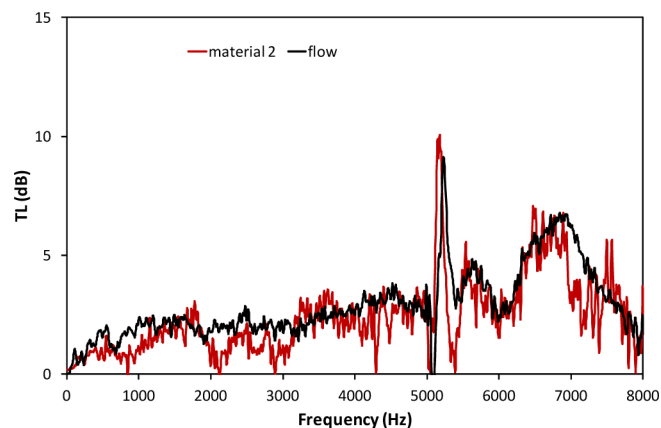


Figure 6. Effect of the flow on the transmission loss: material 2.

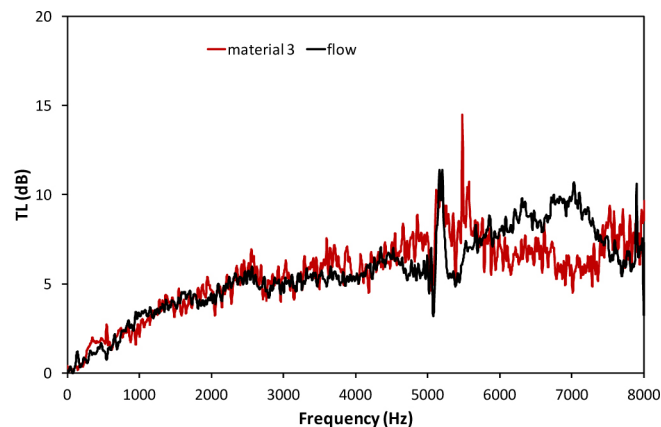


Figure 7. Effect of the flow on the transmission loss: material 3.

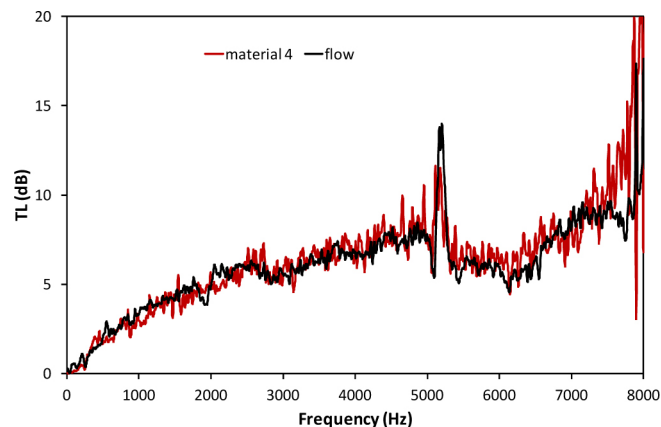


Figure 8. Effect of the flow on the transmission loss: material 4.

The effect of the superimposed mean flow is shown separately for the four devices considered in Figs. 5 to 8. A Mach number of 0.05 was imposed. It can be observed that, except in the case of material 2, the low to mid frequencies are not significantly affected by the presence of the flow. For high frequencies, a certain increase in the attenuation is observed for materials 1 and 3, while materials 2 and 4 do not exhibit significant changes. In any case, one can observe that the presence of the flow does not introduce dramatic changes in the behavior of the devices. In fact, the conclusion would be that either in