

Design of a Multi-Chamber Silencer for Turbocharger Noise

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ABSTRACT

A multi-chamber silencer is designed by a computational approach to suppress the turbocharger whoosh noise downstream of a compressor in an engine intake system. Due to the significant levels and the broadband nature of the source spanning over 1.5 – 3.5 kHz, three Helmholtz resonators are implemented in series. Each resonator consists of a chamber and a number of slots, which can be modeled as a cavity and neck, respectively. Their target resonance frequencies are tuned using Boundary Element Method to achieve an effective noise reduction over the entire frequency range of interest. The predicted transmission loss of the silencer is then compared with the experimental results from a prototype in an impedance tube setup. In view of the presence of rapid grazing flow, these silencers may be susceptible to whistle-noise generation. Hence, the prototype is also examined on a flow bench at varying flow rates to assess such flow-acoustic coupling. The resulting configuration has provided a satisfactory control of the whoosh noise.

1. INTRODUCTION

Turbochargers have been extensively used in diesel (as well as more recently gasoline-direct-injection) engines to improve their performance. However, due to their operation at high speeds, turbochargers are susceptible to noise generation such as whine (narrow band) and whoosh (broadband). While unbalanced blades contribute to the former, the latter is due to turbulence. Such noise can be radiated from the structure, especially from the duct segment between the compressor and intercooler. The characteristics of turbocharger noise have been addressed by, for example, Trochon [1] and Evans and Ward [2]. Evans and Ward [2] showed that the compressor outlet was a major contributor to the overall intake system noise and experimentally demonstrated the effectiveness of a thicker wall and a resonator to reduce turbocharger noise. Stoffels and Schroeder [3] also showed that a silencer could reduce both whine and broadband noise. Trochon [1] developed a combination of Herschel-Quincke tube (HQT) and quarter-wave resonators to reduce the broadband flow noise. Graefenstein and Wenzel [4] also used the HQT in the shape of a spiral for the suppression of turbocharger noise. The HQT may be effective in reducing broadband flow noise at high frequencies (1.5-3.5 kHz) [1, 4]. However, it requires a

relatively large space and the associated resonance frequencies are very sensitive to the variation of lengths. For example, Graefenstein and Wenzel [4] observed that small variations in acoustical path lengths could change the acoustic behavior considerably.

Compared to the HQT, Helmholtz resonators (HRs) may require relatively smaller space for a comparable broadband noise reduction. HRs have been used extensively due to their effective attenuation characteristics, though confined to the vicinity of the resonance frequency [5]. To address the relatively broadband noise of whoosh, therefore, a multi-chamber HR, as shown in Fig. 1, has been considered in this study. The resonance frequencies of each resonator are carefully tuned to achieve significant levels of noise reduction over the frequency range of interest.

One-dimensional approach has been used by Trochon [1], and Graefenstein and Wenzel [4] for the predictions of Herschel-Quincke type resonators with the assumption of small diameters for both the main duct and side branch. However, for the HR, a multi-dimensional analysis may be required for the prediction of its acoustic behavior because the cavity dimensions may be large enough for propagation of the higher modes possibly coupled with a complex geometry. Three-dimensional numerical approaches, such as

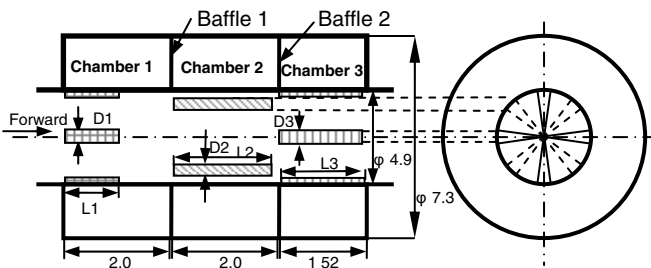


Figure 1. Schematic of a multi-chamber Helmholtz resonator [unit: cm].

Finite Element Method and Boundary Element Method (BEM), may be suitable to predict the acoustic behavior of a HR at high frequencies. The BEM approach is used in the present study in combination with the measured acoustic impedance of rectangular slots to predict the transmission loss. Guided by these predictions, two prototypes are fabricated for the experimental validation. The predictions are then compared to the transmission loss measured on an impedance tube setup.

Since the silencer is in direct contact with high speed flow, it is susceptible to whistle noise generation. The mechanism of whistle noise is well explained by, for example, Radavich and Selamet [6]. Such narrow-band noise is so distinguishable that it may be audible outside the silencer. Thus, the final prototype is examined also

in a flow bench at different flow rates to determine if it generates whistles. Following this introduction, Section 2 describes the prototypes and Section 3 introduces the BEM briefly as applied to the current silencer, and compares the predicted and measured results. The study is concluded in Section 4.

2. PROTOTYPES

Figure 1 shows the schematic of the three-chamber HR developed in this study. Each chamber incorporates four slots which are oriented primarily parallel to the main duct axis, 90° apart around the perimeter, and 0.09 cm in wall thickness. Each of these chambers acts as a cavity and the corresponding slots can be modeled as the neck of the resonator. Dimensions, including the overall length of the silencer (5.52 cm), and the inner (4.9 cm) and outer diameters (7.3 cm) of the chambers, are dictated by the space constraints in the vehicle. The chambers are fixed but slot dimensions are varied to tune the resonance frequencies as shown in the Table 1. The thickness of walls (baffles) separating the chambers is 0.163 cm. The minimum target transmission loss is 15 dB in the frequency range of 1800 – 2800 Hz, in the absence of mean flow at room temperature.

Table 1. Slot dimensions of two prototypes [unit: cm]

	L1	D1	L2	D2	L3	D3
Prototype 1	1.016	0.8	2.0	0.475	1.52	1.13
Prototype 2	2.0	0.318	2.0	0.475	1.52	1.11

3. NUMERICAL AND EXPERIMENTAL RESULTS

3.1 BOUNDARY ELEMENT METHOD

The boundary element method is a useful tool to predict the acoustic performance of silencers with complex geometry and/or in the presence of multi-dimensional wave propagation. A brief description of the BEM approach as applied to the current configuration follows next, while leaving the details to earlier publications, for example, by Ji *et al.* (1994) [7] and Selamet *et al.* (2003) [8].

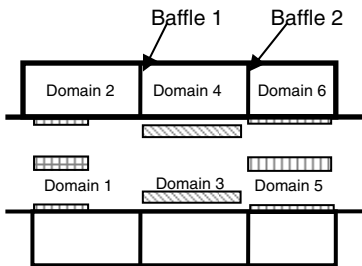


Figure 2. Domains in the BEM model.