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Analysis and design guidelines for fork muffler with H-connection ☆

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ABSTRACT

The Herschel-Quincke (H-Q) tube phenomenon has been applied to favorably alter the performance of the Fork muffler (or dual muffler) by interconnecting the two halves of the fork muffler system by means of a tube (H-connection). Although there is only one additional tube in the inter-connected fork muffler (fork muffler with H-connection), yet it substantially changes the acoustic impedance felt at the source. In order to understand the effect of the H-connection, we need to carry out the analysis of the whole exhaust system. This paper first deals with the analysis of the fork muffler (which falls under the category of single-inlet multiple-outlet muffler) with and without H-connection using the transfer matrix approach, the results of which have been validated by a means of a 3-D finite element analysis. In general, the convective effect of the mean flow plays very little role in the performance of the muffler. But, the mean flow effect at the H-junctions may be crucial to the effectiveness of H-connection and its effect has been taken into account in the parametric study of the fork muffler with H-connection. The dissipative effect of the mean flow at the perforations has been considered throughout the analysis. The parametric study of the fork muffler with H-connection is then carried out to construct the design guidelines for efficient use of the H-connection in designing exhaust systems.

1. Introduction

For paucity of space under the vehicle, a given muffler system may be divided into two identical mufflers of the same (desirable) length, but with half the cross-sectional area of the respective exhaust pipe, tail pipe, intermediate pipe and the muffler shell (Fig. 1). Fork mufflers (or dual mufflers) are very commonly used for high volume engines (engines with high mass flow rate, for example V6 engines), as splitting the muffler into two thinner mufflers eases the design process. Fork mufflers are also preferred to improve subjective noise; i.e., in addition to reduction of its overall sound pressure level (SPL), the noise spectral components at the low as well as high frequencies are optimized to improve the tone of the vehicle exhaust noise as perceived by the customers. The performance of the fork muffler may be favorably altered by inter-connecting the two mufflers, as phase cancellation may be enhanced by the inter-connecting pipe between the two mufflers. This phenomenon of phase cancellation by inter-connecting two components is known as Herschel-Quincke (H-Q) tube phenomenon. The Herschel-Quincke (H-Q) tube is a simple implementation of the interference principle in an acoustic attenuation device: two ducts of arbitrary length and section (within reasonable limits) in a parallel arrangement [1].

A thorough study of the acoustics of the H-Q tubes was presented by Selamet et al. [2]. They eliminated the restrictions of equality of cross-sectional areas of the parallel ducts and the equality of the sum of the cross-sectional areas of the two branch ducts with that of the entrant or exit duct, and indicated that the attenuation obtained is not limited to sharp peaks. This concept can be effectively used for automotive applications as well. Thus, H-Q tube can be an interesting alternative to other resonating devices like concentric tube resonator or Helmholtz resonator [3]. Selamet et al. [4] also extended the concept of the H-Q tube from the two-duct system to the n-duct system and obtained a closed form expression on the transmission loss (TL) characteristics as well as for resonance location. Panigrahi and Munjal [5] later extended the work of Selamet et al. [4] to analyze a general network of 2-port acoustic filters interconnected to each other. Their work was not only confined to modified H-Q tubes (where the inlets and outlets of all the N ducts were connected together), but in general could analyze a network of 2-port elements connected in an arbitrary manner. However their investigation was limited to the overall network having only a single-inlet and single-outlet.

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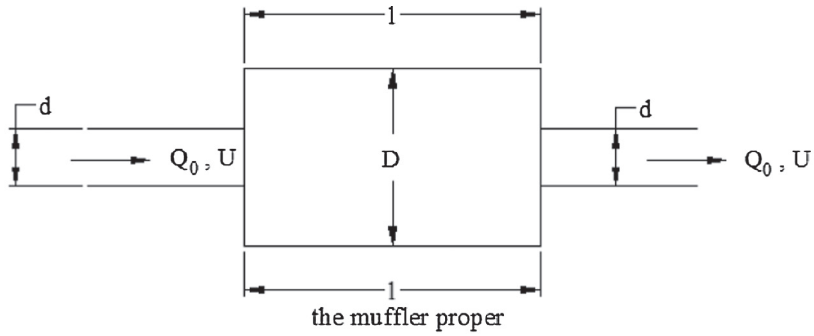
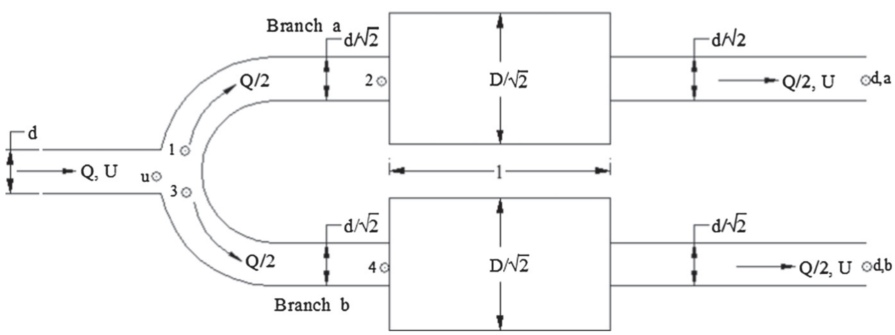


(a) – Schematic diagram of the single muffler configuration.



(b) – Schematic diagram of the equivalent Fork muffler configuration

Fig. 1. Schematic diagrams of the single muffler configuration and its equivalent Fork muffler configuration (the rectangular boxes shown in the above two figures are the three-pass double-reversal muffler with tubular bridges whose details are shown in Fig. 2).

This concept of the H-Q tube has been successfully applied to attenuate the exhaust noise from internal combustion engines. Various designs patented over the years show the successful implementation of the H-Q tube phenomenon in exhaust systems [6–11]. The concept of H-Q tube has been also successfully applied in turbocharger noise control by Trochon [12]. He applied the combination of quarter-wave resonators and parallel ducts (H-Q phenomenon) to obtain the attenuation for a wide span of frequencies. Burdisso et al. [13] have also implemented the H-Q tube phenomenon for the reduction of tonal and broadband noise from a turbofan engine indicating wide application areas for the H-Q phenomenon. Desantes et al. [14] have shown the effect of interconnecting the parallel ducts of the H-Q tube. He has shown the influence of the connecting pipe on the resonance frequencies.

In this paper the effect of inter-connecting the two constituent mufflers is studied to arrive at some design guidelines. From the analysis point of view, the fork muffler falls under the category of single-inlet multiple -outlet muffler. There are certain algorithms available in literature to analyze these systems. Wu et al. [15] analyzed the acoustical performance of a single-inlet double-outlet cylindrical expansion chamber muffler using the modal meshing approach and the plane wave theory, respectively. They did the parametric study for different values of the length-to-diameter ratio, and presented the computed TL results in order to demonstrate the higher order effects. Glav and Abom [16] extended the work of Eversman [17] and presented a general algorithm for the analysis of sound propagation in 2-port networks. They removed the limitations of only one active port by allowing the 2- ports as well as the joints (the nodes) to be active. Their algorithm was computationally more efficient than that of Eversman [17]. Mimani and Munjal [18] presented an algorithm to analyze a general network of linear passive acoustic filter having multi-port elements, which are inter-connected in an arbitrary manner through their respective ports or through general 2-port elements. Generalized expressions were obtained for the determination of the acoustic performance parameters (like transmission loss (TL), insertion loss (IL)) in terms of the impedance matrix. Yang and Li [19] presented a sub-system strategy to analyze the acoustic performance of network systems. They divided the whole system into several substructures according to the dimensions and geometry of the substructure and then applied the appropriate strategy (Boundary element method (BEM), numerical point collocation approach and numerical mode matching technique) to obtain the impedance matrix of each substructure module. Impedance matrix synthesis was employed to obtain the resultant impedance matrix and then the TL of the whole network was calculated. Although different algorithms stated above could be used for the analysis of fork muffler systems, they would be unnecessarily much more involved as the transfer matrices of the constituent mufflers are known a priori [20]. In this paper the analysis has been done using transfer matrix approach.

Considering the application of the H-Q tube in the exhaust systems of internal combustion engines, the effect of the mean flow may not be negligible [21]. Zhichi et al. [22] have shown the effect of the flow on the transmission loss. They have also shown that the frequency of the maximum transmission loss is modified by the flow. Their results also indicate that the flow effects on the upstream and the downstream sound propagation are similar, and the effect of the flow on the noise reduction can be ignored when the mean flow velocity is small. Torregrosa et al. [23] studied the effect of the mean flow on the acoustic behavior of the classical two duct configuration. They obtained the transfer matrix with mean flow which depends explicitly on the geometry and on the flow Mach number in the branch. Their results show that the influence of mean flow arises in both senses, that is in modifying the attenuation levels, as could be expected, and changing qualitatively the shape of the attenuation curve. Karlsson et al. [24] also studied the effect of the mean flow on the attenuation condition