Journal of Sound and Vibration 430 (2018) 185–195

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Analysis on acoustic performance and flow field in the split-stream rushing muffler unit

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A R T I C L E I N F O

Article history:
Received 4 May 2017
Received in revised form 11 April 2018
Accepted 16 April 2018

Handling editor: L. G. Tham

Keywords:
Exhaust noise
Split-stream rushing
Muffler unit
Transmission loss

A B S T R A C T

Airflow velocity is a dominant factor of influencing exhaust resistance and turbulence noise in exhaust muffler of internal combustion engine. In this paper, a new principle of reducing the airflow velocity, based on split-stream rushing in muffler, was proposed. The main idea of this principle is to split the exhaust airflow into two streams first, and then lead them rushing when meeting from two opposite-located holes so that achieve the result of reducing the exhaust airflow velocity through the muffler. The basic structure of the split-stream rushing muffler unit was presented and its acoustic performance was analyzed by using the acoustic wave theory. Finally, the numerical simulation and experimental way were used to verify the internal sound field and velocity changes in the new muffler unit. The results show that the proposed muffler unit can effectively reduce the exhaust airflow velocity through the silencer and exhaust backpressure.

1. Introduction

The internal combustion engine (ICE) has still been being widely used in power machine nowadays, which is not only applied in vehicles, ships, small aircraft etc., but also in engineering machinery, agricultural machinery and mobile power station facilities. At the ease of power supply in industry, its noise pollution has a tremendous impact on surrounding environment and the operator. In the noise sources of the ICE or the vehicles powered by ICE, the exhaust noise is the dominant compared to other noise sources, such as the component-vibration noise, inlet-air noise and so on [1], so it is very important to control the exhaust noise in reducing the engine or vehicle's whole-machine noise, and the simplest and most effective way to deal with this problem is to install the exhaust muffler [2]. As a result, the research on developing the new type of effective muffler has been the hot topic up to now.

The study on exhaust muffler was started in 20s of last century. The traditional exhaust muffler is mostly of a reactive muffler based on the acoustic filter theory, which reduces the exhaust noise by using the varied cross-section structure or bypass pipe to cause the acoustic impedance mismatch or resonance interference. In 50s of twenty century, Davis D D, et al., analyzed the noise-reduction principle of muffler by using the acoustic transfer matrix method of one-dimensional acoustic theory and did the experimental verification, which has laid the foundation of muffler research theory [3–5]. The one-dimensional acoustic theory, the fundamental theory in muffler design presently, has a high accuracy in calculating the sound wave propagation within the muffler's cut-off frequencies. With the development of computer technology, numerical

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https://doi.org/10.1016/j.jsv.2018.04.025

simulation has been used more and more in muffler design, which is especially favorable for analyzing the high-frequency sound wave and higher harmonics.

Li Gen et al., reviewed the recent development of muffler, including the research methods for noise-reduction performance of muffler, relationship between the noise-reduction performance of different structured muffler unit and its exhaust back pressure, as well as the muffler structure optimization [6–9].

The former scholars have made a great contribution to the development of the muffler, but the works were mainly focused on the researches of exhaust noise reduction obtained by changing or by optimizing the structure of the reactive muffler, lacking of the studies on new principle or new type of the muffler.

A very important factor affecting the performance on exhaust muffler of internal combustion engine is the airflow velocity in muffler. The sound power of turbulence noise in muffler is approximately proportional to 6th power and exhaust resistance is proportional to 2nd power of the airflow velocity in muffler respectively [10–12]. As Li Gen mentioned in his research, airflow in the muffler has an important influence on acoustic performance of the muffler [6]. Kojiman et al. investigated the airflow noise generated by the steady flow for the simple cavity type mufflers and the perforated straight-through-pipe type mufflers, concluded that the air flow has a great influence on noise generation in muffler in 1987 [13]. Liu L.'s research also indicated that the sound reduction of muffler will decrease as the airflow velocity increases in 2001 [14]. Du J. found that the airflow velocity has a close relation with vortex generation mode in muffler in his research in 2010 [15]. Li Haibing, Li Yinong and Huang Qibai et al. have also studied the flow field inside the muffler, pointed out that the high-velocity airflow in the muffler will result in the turbulence generation in muffler and deteriorate the noise-reduction performance [16–18].

Although the scholars have a common view that the airflow velocity in muffler is significant in muffler's performance, any effective way in reducing it from the principle has not been found so far.

In this paper, a so called “split-stream-rushing” muffler unit was proposed in which the idea is to reduce the exhaust airflow velocity by action of the rushing of two split streams in muffler, so that it will have a potential in lowering both the turbulence noise and back-pressure in muffler.

2. Principle of the split-stream rushing muffler unit

The structural sketch of the new split-stream rushing muffler unit is shown in Fig. 1. When the exhaust airflow (about 30 m/s–60 m/s) from ICE enters into the split-stream rushing muffler unit, it will be directed into the annular region by a conical structure firstly, then flows into each interior chamber through two radial circular holes, which have the same size, but located at opposite sides, so the flow stream is split into two out-of-phase branches and rushing each other in the center of each interior chamber, thus the velocity of mixed flow stream is lowered.

3. Analysis of the aerodynamic properties of the split-stream rushing muffler unit

3.1. Analysis of internal flow field for the new muffler unit

In order to understand the mechanism of exhaust airflow velocity reduction in the split-stream rushing muffler unit, the CFD (Computational fluid dynamics) method was used to simulate its internal flow field [19]. The CFD model based on the structure is shown in Fig. 2. The specific dimensions are as follows: $l_1 = 100$ mm, $l_2 = 40$ mm, $l_3 = 10.5$ mm, $l_4 = 50$ mm, $D_1 = 42$ mm, $D_2 = 70$ mm, $D_3 = 100$ mm, $D_4 = 56$ mm, $D_5 = 24$ mm. Sound velocity $c = 346$ m/s; air density $\rho = 1.186$ kg/m^3.

A 3D model was meshed with mesh size of 5 mm in Gambit software (Gambit software version is 2.3.16), and then it was imported into the Fluent software (Ansys Fluent software version is 14.0.0.) for simulation. The boundary condition for the computation was assumed as: fluid material is atmosphere in room temperature and in atmospheric pressure, airflow is a steady flow with inlet velocity of 30 m/s and free outlet, the wall is adiabatic and smooth. The solution type is based on the velocity of the coupled solver [20].

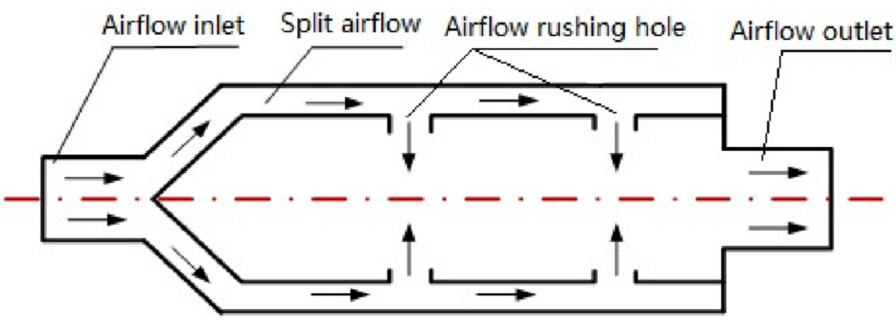

Fig. 1. Structural sketch of the split-stream rushing muffler unit.