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The Influence of Perforation Parameters of Hydraulic Muffler on Turbulence Noise

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Abstract: The turbulence noise, which has significant influence on the acoustic attenuation performance of the muffler, is always ignored in the process of design mufflers, it leads to the noise attenuation performance of the muffler is not consistent with the prediction performance. In this paper, the influence of the main perforation parameters of perforated tube on turbulence noise is studied by the broadband model of ANSYS fluent, the results show that the turbulence noise is least when the perforated rate is about 15%. The inner flow field of the muffler has less turbulence noise when the thickness of the perforated tube is thicker and the orifice diameter of the perforated tube is smaller. The turbulence noise is least when the ratio of inner diameter of perforated tube and the inlet diameter is equal to 1, and the turbulence noise is also increased with the increasing of the ratio.

Keywords: Turbulence noise; perforation parameters; turbulence kinetic energy.

INTRODUCTION

With the development of industry and science technology, the vibration and noise in hydraulic pipeline system are got more and more attention, the fluid vibration and noise in hydraulic system can be divided into two categories, the one is source noise that is generated by power source, such as pressure pulsation caused by hydraulic pump cyclical movement. The other one is turbulence noise that is generated by flow of fluid, such as the flow in the palace of structure sudden changes. Generally speaking, there are three kinds of methods to restrain the source noise of hydraulic pipe system [1], the first method is reducing the flow pulsation of pump, valves and other piping components. The second method is reducing the input impedance of the hydraulic system, the pressure pulsation will be reduced in the same flow condition. The last method is installing liquid muffler or other auxiliary equipment in the pipeline to attenuate and filter pressure pulsation and noise. The first two methods can not completely avoid the occurrence of pressure pulsation, so, installation of fluid muffler or other auxiliary equipment in the pipeline is a necessary method to reduce the vibration and noise of hydraulic system. However, the turbulence noise is always ignored in the process of design muffler, it leads to the acoustic attenuation performance of the designed muffler is not consistent with the prediction performance.

A simple perforated muffler is mainly combined of inlet pipe, outlet pipe, expansion chamber and perforated tube, as shown in Fig. 1. The expansion chamber is widely used in muffler for its broadband attenuation characteristics, but it would lead to high flow loss. The perforated tube has good performance of reduce flow loss and improve acoustic attenuation performance in special frequency range [2-4], so, the perforated tube is an important component of muffler. The parameters of perforated tube has significant influence on mufflers performance [5]. In previous papers, there are some optimization work for gas mufflers. Y.-C. Chang[6] and Chiu, M. C[7] used genetic algorithm (GA) to optimize one-chamber and multi-chamber perforated muffler's shape parameters under space-constrained condition. To proficiently enhance the acoustical performance within a constrained space, Ying-chun Chang et al. provided a simulated annealing (SA) algorithm which is imitating the softening process of metal to optimize the structure parameters of a multi-chamber side muffler hybridized with reverse-flow ducts which can visibly increase the acoustical performance [8]. NSGA-II genetic algorithm was used to optimize the overall structure of muffler to make the TL maximum at multiple frequency ranges [9]. A. Selamet et al, studied the location of the inlet and outlet ports, his research results shown that an appropriate position of the inlet and outlet port location can suppress the propagation of higher order modes, and result in a broadband attenuation [10]. A. Mimani et al, optimized the chamber length and port location of elliptical chamber mufflers using a 3-D semi-analytical piston driven model [11]. Kenneth A. et al. also have done some research about hydraulic mufflers, a linear mutimodal model is developed for a pressurized gas bladder style hydraulic noise suppressor to predict the attenuation frequency, the model considered the influence of perforate layer impedance and inlet/outlet extensions [12-14].

In this paper, the turbulence noise of different perforated tube parameters of the muffler is obtained by using the Fluent software, and the influence laws of perforated tube main parameters on turbulence noise is got.

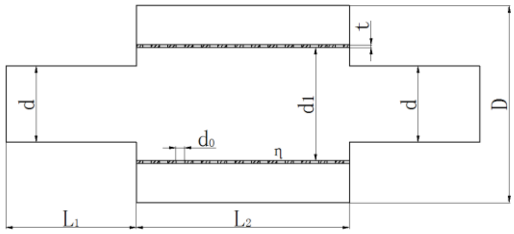

FIG. 1 Geometry of hydraulic perforated muffler

2. Numerical Method

Because the numerical method has the advantages of economy, high efficiency and accuracy, the numerical simulation method is widely used to product design. Fluent has a powerful function of calculation flow field distribution, it can be used to predict the flow noise of the muffler. There are three models of prediction flow noise in Fluent, they are the CAA model, FW-H model and broadband model, respectively. The CAA model need high precise solve method, precise grids and non-reflection boundary condition, so the calculation cost is very high. FW-H model is the supplementary to CAA model, through decoupling the wave and flow equation, then make the flow equation solution as a noise source to solve wave equation, the calculation cost is also high. The turbulence is obtained through RANS equation in broadband model, and then use a semi-empirical correction model to calculate the surface unit or volume unit noise power. The broadband model only need steady calculation, but the other two model need transient calculation, so the calculation cost of broadband model is much lesser than the other two model, it is suitable for product rapid design.

In this paper, broadband model is used to predict the turbulence noise of the muffler, different methods were used by Proudman [15] and Lilley [16] to derive the acoustic power that caused by unit volume of isotropic turbulence, both derivations yield acoustic power due to the unit volume of isotropic turbulence as:

$$P_A = \alpha\rho_0\left(\frac{u^3}{\ell}\right)\frac{u^5}{a_0^5} \tag{1}$$

Where u and ℓ are the turbulence velocity and length scales, respectively, a_0 is the speed of sound, α is model constant.

The acoustic power also can be described by turbulent kinetic energy k and the dissipation rate ε:

$$P_A = \alpha_\varepsilon \rho_0 \varepsilon M_t^5 \tag{2}$$

$$M_t = \frac{\sqrt{2k}}{a_0} \tag{3}$$

Where, α_ε is rescaled constant, it is set to 0.1 in ANSYS Fluent.

The acoustic power level (APL) is defined as:

$$L_P = 10\log\left(\frac{P_A}{\mathrm{P}_{ref}}\right) \tag{4}$$

Where, P_{ref} is reference acoustic power, its value is 10^{-12}W/m^3.

3. Mesh and boundary conditions

The mesh region of a simple perforated muffler are composed of inlet region, outlet region, expansion chamber and perforated tube region, as shown in Fig. 2. As the diameter and thickness of the perforated tube are small, the no-structure mesh is used. The grid density is increased in the place of diameter to satisfy the calculation needing. The medium is hydraulic oil in the muffler, its density is 900kg/m^3, the propagation velocity of acoustic wave in oil is 1400m/s, the reference acoustic power is 10^{-12} W/m^3, the k-epsilon turbulence model is used, the inlet velocity and outlet pressure are set as 8m/s and 8MPa respectively, the roughness of the wall is 0.0032mm.

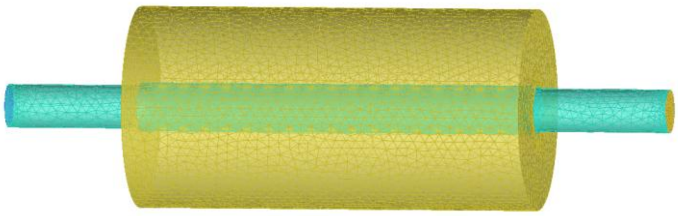

Fig. 2 Mesh of the perforated muffler

4. Results and discussion

As the APL can represent the turbulence noise, the APL distribution is used to describe the turbulence noise that generated by the structure change of muffler. The APL distribution of perforated mufflers is obtained by broadband model of ANSYS fluent, as the structure of muffler is axial symmetry, so a vertical section is used to describe the acoustic power distribution.

4.1 Influence of perforate rate

The perforated rateβis the ratio of the total orifice area and the outer surface area of perforated tube. When the perforated rate increases from 5% to 65%, the APL distribute in a vertical section of the muffler is shown in Fig. 3. The APL nearby the outlet of perforated tube increased about 10 dB when the perforated rate is bigger than 35%, and the APL nearby the orifice of perforated tube inlet is increased about 6 dB when perforated rate is bigger than 50% or lower than 5%. The APL of inlet and out region is least (about 9dB) when the perforated rate is 15%. Fig. 4 is the turbulence kinetic energy distribution in a vertical section when the perforated rate is 50%, it shows that the turbulence kinetic energy is concentrated on the place of nearby the orifice, it is consistent with the distribution of APL. So the acoustic performance of mufflers can be improved by improvement the flow flied of nearby the orifice.

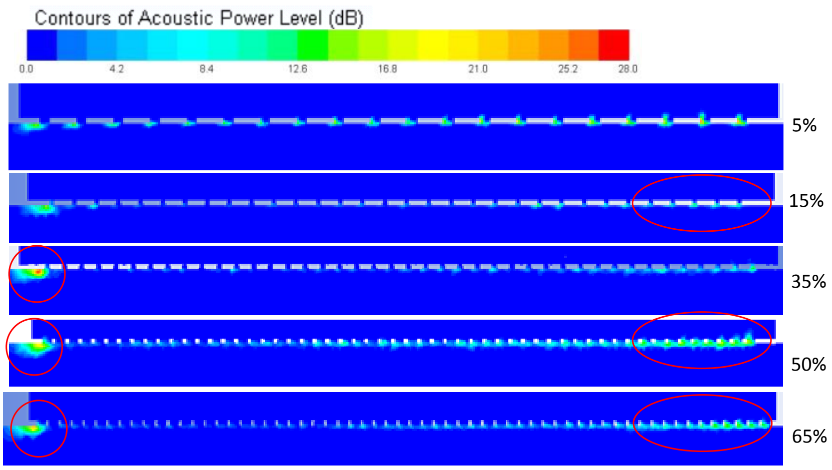

Fig. 3 APL distribution of different perforated rate

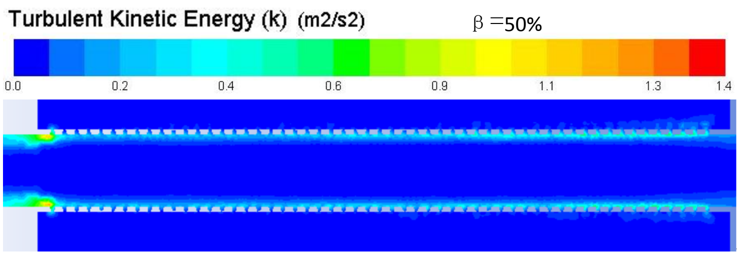

Fig. 4 Turbulence kinetic energy distribution of β=50%

4.2 Influence of perforated tube placement

Fig.5 shows the APL distribution when the ratio λ of inner diameter of perforated tube to the inlet diameter gradually increases from 1 to 4.3. The APL is least when the ratio is equal to the 1, which means the inner diameter of perforated tube is equal to the inlet diameter. With the increase of the ratio, the APL in the region of nearby outlet rapidly increases from10 dB to about 40 dB and in the region of expansion chamber region t rapidly increases from 0 dB to 20 dB, furthermore, the bigger the inner diameter of perforated tube is, the more obviously the tendency is. Fig. 6 is the turbulence kinetic energy distribution in a vertical section when the perforated tube placement is 0.5, it also consistent with the APL distribution.

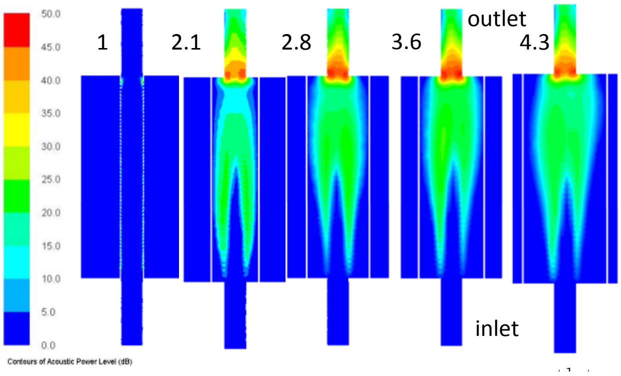

Fig. 5 APL distribution of different perforated tube placement

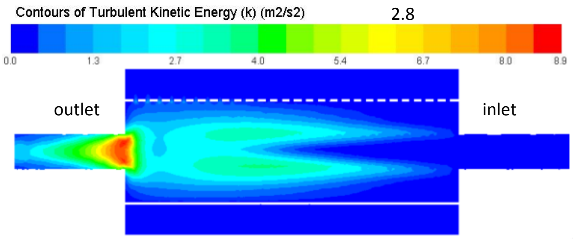

Fig. 6 Turbulence kinetic energy distribution of λ=2.8

4.3 Influence of perforated tube thickness

The APL decreases with the increase of perforated tube thickness, but the scale is small, as shown in Fig. 7. This is because that the orifice caused flow resistance, which will consume some turbulence energy. As the perforated tube thickness is not thick enough, the consumption of turbulence energy is not significant. Fig.8 shows the turbulence kinetic energy distribution in a vertical section when the thickness of perforated tube is 2mm. The turbulence kinetic energy is also concentrated on the place of nearby orifice, which is the same with the APL distribution

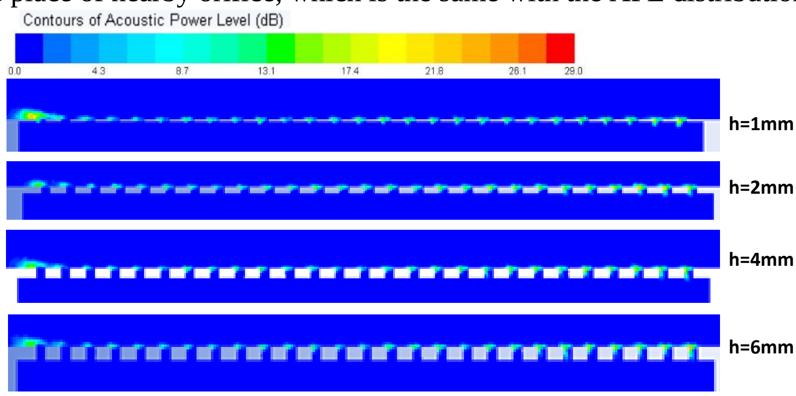

Fig. 7 APL distribution of different perforated tube thickness

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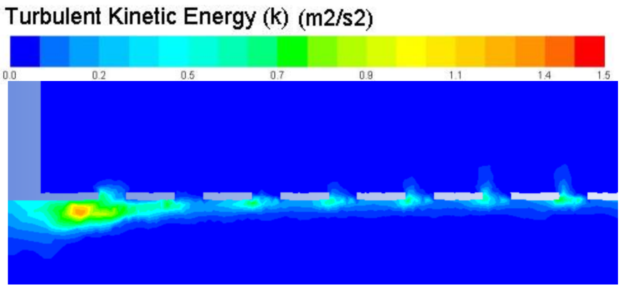

Fig. 8 turbulence kinetic energy distribution of *h*=2mm

4.4 Influence of perforated tube orifice diameter

When the orifice diameter of perforated tube *d* increases form 2mm to 6mm, the APL distribution is shown as Fig. 9. The APL has little change when the orifice diameter is less than 4mm, but the APL in the area of closed to outlet orifice is obviously increased when the orifice diameter is up to 6mm. This is because that the restrain ability of orifice to flow is more obvious when the diameter is less than 6mm. Fig. 8 shows the turbulence kinetic energy distribution in a vertical section when the orifice diameter is 2mm. The kinetic energy is also concentrated on the place of nearby orifice, which is the same with the APL distribution.

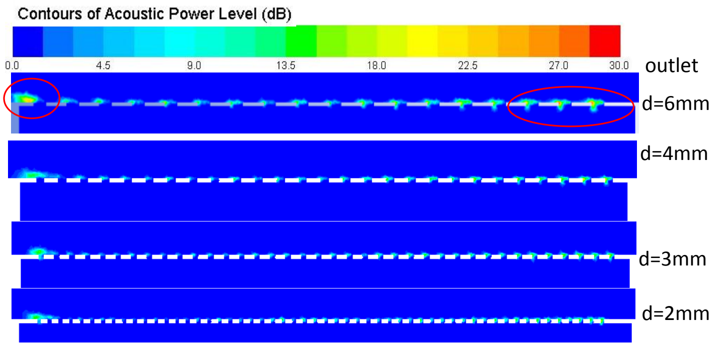

Fig. 9 APL distribution of different perforated tube orifice diameter

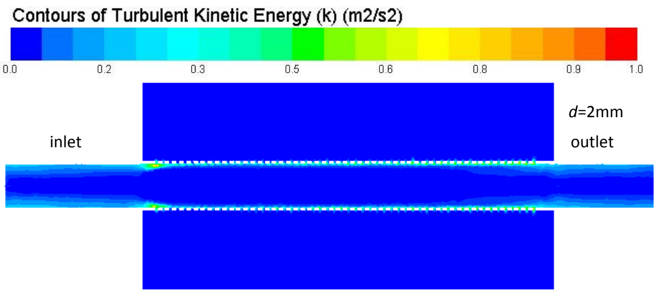

Fig. 10 Turbulence kinetic energy distribution of *d*=2mm

5. Conclusion

The broadband model is used to predict the APL distribution of the simple perforated tube, the effects of the main perforation parameters on the APL of the muffler is studied. The results show that the perforated tube can effectively restrain the turbulence noise when the inner diameter of the perforated tube is equal to inlet diameter. The turbulence noise is least when the perforated rate is about 15%. The muffler has less turbulence noise when the thickness is thicker and the orifice diameter of perforated tube is smaller. The results also show that the distribution of turbulence kinetic energy is consistent with the distribution of APL. The research results proved several useful advice for the design of hydraulic muffler.

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