Experimental study on noise reduction effect of a muffler inserted in liquid transporting pipeline

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Abstract. In order to reduce the noise of liquid transporting pipelines caused by the motion of the power unit, a kind of compact hydrodynamic muffler used in pipes with small diameters is proposed which achieves good vibration damping as well as hydrodynamic noise reduction. Based on the rubber damper tube, according to the structure characteristics, the muffler is composed of two main parts, the rubber damper tube and the inner noise reducing structure. Experiment on insertion loss of the muffler in stationary state is conducted. It is found that the rubber damper tube itself has a good performance at noise reducing at the frequency band considered here, total insertion loss values can reach 10 dB and the inner structures improve the performance of the muffler at low frequency band.

1. Introduction

In industry field, displacement pumps and centrifugal pumps are commonly used for fluid transport, and they are the main noise source of the piping system. During the pump working process, vibration and noise induced by the mechanical structure, fluid pulsation and rotor-stator interaction will propagate to downstream equipments and working environment through the connected pipelines and fluid in them, which will affect the system control precision, and even affect the normal work of the downstream equipments. [1][2] And for the field which is strict with the noise propagation, especially in the military use, such as ship and underwater equipment, propagation of the vibration and noise will decrease the hiding ability of the equipment, which means decreasing of equipment’s performance. Therefore, the noise of liquid transporting pipeline should be effectively controlled in many fields. [3]

Most of the researches on mufflers/silencers are focusing on the air muffler. The early work on the water muffler is about muffler with large diameters. Li Ying [4] and Wang Qiang [5] designed and studied the wide spectrum muffler or bladder type silencer. Yuan Jianping [6], Zhou Chengguang [7] and Gao Lin [8] studied the property of Helmholzt muffler used in water situation. Xu Weiwei [9] and Yang Liangjun [10] studied water expanded muffler with internal spile. With regard to mufflers with large diameters, noise reduction can be done through adding sound absorption materials and designing and installing various forms of hydrodynamic mufflers. However, as to mufflers with diameters less than 30 millimetres, with no enough space for the installation of the sound absorption materials, the hydrodynamic muffler is the best choice here to control the noise in the pipeline. In this article, based on the rubber damper tube, according to the structure characteristics, a kind of compact hydrodynamic muffler is proposed to reaching a good vibration damping as well as hydrodynamic noise reduction performance.
Insertion loss and transmission loss are the parameters wildly used to describe the acoustic performance of a muffler and/or its associated piping. Selamet A [11] used the insertion loss to determine sound attenuation characteristics of the Helmholtz resonator in the intake system of internal combustion engines. Koussa F [12] used the insertion loss to evaluate the acoustic performance of conventional and low height gabions noise barriers. Lee Y Y [13] studied the insertion loss of a cavity-backed semi-cylindrical enclosure panel. Mimani A [14] evaluated the acoustic performance of an elliptical chamber muffler having an end-inlet and side-outlet port in terms of transmission loss. Selamet A [15] used the transmission loss to evaluate the acoustic performance of a concentric circular Helmholtz resonator lined with fibrous material. This paper will focus on measuring IL of a muffler. Test equipment and test method of the hydrodynamic noise and experiments on the noise reduction performance of the pipelines and mufflers with different structures are introduced. Effect of muffler parameters on the noise reduction performance are analysed here. The experimental results can provide reference for the design of vibration damping and noise reducing structure used in small diameter liquid transportation pipeline.

2. Experiment arrangements

2.1. Experimental setup
A schematic of the test arrangement is shown in figure 1. Two tanks of different sizes are connected by test pipes. The bigger one here is used to ensure the test pipes filling with water. Size of the smaller water tank is 0.5m x 0.5m x 0.5m, and the water depth in the tank is 0.4m. The noise generated by a loudspeaker in the smaller water tank is measured. Size of the loudspeaker is 50mmx50mm. The loudspeaker was placed 0.2m below the water surface and the working plane is addressed normal to the outlet pipe of the tank.

In order to acquire the sound pressure data downstream of the muffler, a hydrophone used to detect acoustic signals is arranged at the measuring point 0.2 m from the test tube along the horizontal direction and the hydrophone is mounted in the middle of the tube. Sound pressure signals are recorded continuously for 50s using a digital audio tape recorder. One-third octave bands and real-time spectra are calculated simultaneously and averaged over 50s. Change tube is a steel tube of the same length and inner diameter with the muffler. Inner diameter of the test tubes is 25mm.

![Figure 1. Schematic of the test arrangement](image-url)
2.2. Experimental samples
The muffler is composed of two main parts, the rubber damper tube and the inner noise reducing structure shown in figure 2. The two parts are detachable so that when we change the samples, we only have to change the inner structures. The inner structures used here are made of plexiglass as it is easy to open holes on this material, especially the small ones.

Principle of the inner structure is the combination of conical tube, the perforated pipe and the extended-tube resonators, which are typical reactive muffler structures. These structures will reflect a substantial amount of the incident power back to the source by creating a mismatch of characteristic impedances. [16]

Figure 3 shows the inner structure. These samples have the same shape. Differences between them are the diameter of the hole on it, number of the hole in a circle and number of the rows of holes along the central line. Hole-diameters considered here are 0mm, 0.3mm, 0.6mm, 0.8mm, 1mm, 2mm, 3mm and 4mm and they are divided into two groups, as shown in table 1.

| Hole on the cylinder section | Hole on the conic section | Porosity |
|-----------------------------|---------------------------|----------|
| Diameter        | Row NO.*Ring NO. | Diameter | Row NO.*Ring NO. | |
| 0mm            | 0*0                      | 0mm      | 0*0            | 0   |
| 0.3mm          | 9*12                     | 0.3mm    | 2*12           | 0.002 |
| 0.6mm          | 9*12                     | 0.6mm    | 2*12           | 0.011 |
| 0.8mm          | 9*12                     | 0.8mm    | 2*12           | 0.02 |
| 1mm            | 9*12                     | 1mm      | 2*12           | 0.032 |
| 2mm            | 9*12                     | 2mm      | 2*12           | 0.13 |
| 3mm            | 8*6                      | 3mm      | 2*6            | 0.133 |
| 4mm            | 6*5                      | 2mm      | 2*5            | 0.128 |

2.3. Experimental results
Sound pressure levels of mufflers with different inner structures, the change tube and the rubber tube without any inner structures are tested. Results at one-third octave bands are shown in figure 4. The frequency band considered here is 100Hz–3150Hz.
Figure 4. Sound pressure levels of the tested samples

Insertion loss (IL) is defined as the difference between the sound power level without any filter and that with the filter. Symbolically,

\[
IL = L_{W1} - L_{W2} = 10\log\left(\frac{W_1}{W_2}\right) \text{ (dB)}
\]  

(1)

Normally, when the size and shape of the tube and the sound field distribution remains approximately the same, insertion loss equals the difference between the sound pressure level without any filter and that with the filter. That is,

\[
IL = L_{p1} - L_{p2} \text{ (dB)}
\]  

(2)

Insertion losses of rubber tube without inner structures and mufflers with different inner structures at one-third octave bands are plotted in figure 5. The results indicate that the rubber tube has a good performance at the frequency band considered here, especially at the middle frequency. Insertion of the inner structures improves the noise reducing performance at low frequency. And mufflers with different inner structures have almost the same performance in the frequency band considered here. This may because the source we used is not strong enough, and the sound downstream is close to the background sound after the use of mufflers.

Figure 5. Insertion loss of the tested samples

Total sound pressure level is defined as the sound pressure level through the whole frequency band and calculated using the equation below:
\[ L_{p,\text{total}} = 10 \times \log_{10} \left( \sum_{i=1}^{N} 10^\left( \frac{L_{pi}}{10} \right) \right) \text{ (dB)} \]  

Where \( L_{p,\text{total}} \) is the total sound pressure level and \( L_{pi} \) is the sound pressure level of each frequency band.

Total insertion loss due to the muffler is the difference in the \( L_{p,\text{total}} \) with muffler and change tube. Total SPL and total IL are shown in table 2. It can be seen from the table that all the samples had a total IL of more than 10 dB except for muffler with hole-diameter of 0.3mm. The \( L_{p,\text{total}} \) is maximum with hole-diameter of 4mm. But the difference between these two figures is within 2 dB which is negligible.

| Samples     | Total SPL(dB) | Total IL(dB) |
|-------------|---------------|--------------|
| Change tube | 101.44        | 0            |
| 0mm         | 91.10         | 10.34        |
| 0.3mm       | 91.46         | 9.98         |
| 0.6mm       | 90.25         | 11.24        |
| 0.8mm       | 90.50         | 10.94        |
| 1mm         | 90.94         | 10.50        |
| 2mm         | 90.80         | 10.64        |
| 3mm         | 90.95         | 10.45        |
| 4mm         | 90.12         | 11.32        |
| Rubber tube | 91.26         | 10.18        |

3. Conclusion
A kind of compact hydrodynamic muffler is proposed to reaching a good vibration damping as well as hydrodynamic noise reduction performance. Experiment on insertion loss of the muffler in stationary state is conducted. Results show that the rubber damper tube itself has a good performance at the frequency band considered here without any inner noise reducing structure. This may because the rubber material reduces noise by absorbing the vibration energy. Muffler with noise reducing structure inserted in has a better performance at the low frequency band. But the differences of the hole-parameters do not make any difference at the performance. Especially muffler without hole has a good performance as well as the mufflers with holes. Thus, considered the complexity of the structure and difficulty of fabrication, muffler without hole is a better choice to insert in.

More work need to be done. A stronger sound source should be used. And a pump may be used as the power unit, so that performance of the mufflers with flow can be studied.

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