EXPERIMENTAL STUDY ON THE PERFORMANCE OF THE BLADDER TYPE WATER MUFFLER

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The bladder type water muffler is a new type of liquid pipe muffler, by which the pulsating pressure and the acoustic noise of the fluid can be well absorbed. The theory here is the changed pressure generated by the built-in airbag when it meets the pulsating liquid. However, the performance of the muffler depends enormously on the relationship between the inflation pressure of the airbag within the muffler and the pressure of the piping system. In this paper we aim to design a test bench with continuously variable pressure of the piping system to approve their relevance to the performance of the muffler. In the experiment, the optimal state of the muffler is found by adjusting the inflation pressure of the muffler airbag and the pressure of the system pipeline. Meanwhile, the relevance of the inflating pressure in the bladder and working pressure of the pipe system to the performance of the muffler is further verified, which provides a useful guide for the application of the muffler on ships and submarines.

Keywords: water muffler, pulsating pressure, experimental study, piping system

1. Introduction

The hydrodynamic noise of seawater pipeline is one of the most important part of the underwater radiation noise of the warships and submarines. It becomes particularly obvious when other sources of noise are effectively controlled. The amount of the noise produced by the flow of the seawater in the pipeline can be reduced by using the seawater muffler, thereby enhancing the stealth of the ships and submarines when they are sailing in water.

The bladder type water muffler is a new type of muffler applied to the seawater pipelines on ships. The pulsating pressure and the noise of the fluid can be well absorbed by the deformation made when the perforated tube and the annular airbag put in the expansion chamber meets the liquids. Compared with the traditional impedance muffler with an expansion chamber, this type of muffler is smaller while it has a better performance on the noise elimination and low-frequency control as well as a lower resistance loss, which provides it with a prospect future.

For bladder type seawater muffler, although there are clues indicating that it has been applied on US naval vessels, there are very few relevant research materials can be consulted so far due to the reasons of technical secrecy, and there are few scholars who have made a systematic research on the real noise attenuation characteristics and the performance of it. Li Ying[1] calculated the transmission loss of a large
diameter bladder type muffler based on the boundary element method. In the calculation, the bladder was simplified into a sound-absorbing material, but this calculation method did not reflect the real situation of bladder deformation. Huang Xinnan\cite{2} studied the acoustic properties and fluid dynamics of several bladder type water mufflers with gradually decreasing shape volume through simulation calculations and model experiments, and obtained some simple influence laws of the muffler volume on the acoustic performance of the muffler. Zhou Xinlei\cite{3} conducted an experimental study on a bladder type muffler, and considered that the change in the volume of the muffler air chamber has little effect on the insertion loss of the muffler.

Zhuang Wang\cite{4} simplified the bladder type muffler into several simple acoustic units, based on the classical acoustic theory of muffler, and the influence of the stiffness of the inner wall on the transmission of acoustic wave vibration in the inlet and outlet liquid columns and airbags was considered, and a simplified calculation model of the transmission loss of the airbag type seawater pipeline muffler is proposed by the transfer matrix method. Based on this model, the transmission loss characteristics of the bladder type seawater muffler are estimated.

Based on the research of [4], this paper carried out a further experimental research on the performance of the bladder type seawater muffler and designed a seawater pipeline system test bench with continuously variable working pressure. In the experiment, the optimal state of the muffler is found by adjusting the inflation pressure of the muffler airbag and the pressure of the system pipeline. Meanwhile, the relevance of the inflating pressure in the bladder and working pressure of the pipe system to the performance of the muffler is further verified, which provides a useful guide for the application of the muffler on ships and submarines.

2. The performance test method for muffler

2.1 Performance index of the muffler

The acoustic performance of the muffler is mainly measured by the magnitude and the frequency range of the noise reduction. The performance index generally includes the insertion loss and the transmission loss. The transmission loss of the muffler, which is mainly used in the theoretical calculation, refers to the difference between the incident sound power level at the inlet and the transmissive sound power level at the outlet of the muffler. The transmission loss is a natural characteristics of the muffler and it only related to the structure of the muffler Therefore, in the actual engineering measurement, the performance of the muffler is generally evaluated by the insertion loss.

2.2 The definition and measurement method of insertion loss

The insertion loss of the muffler refers to the difference between the sound power level or the sound pressure level of the noise radiated from the source at the measurement point before and after the muffler is inserted between the sound source and the measurement point. If the acoustic field distribution remains approximately the same before and after the installation of the muffler, the insertion loss is equal to the difference between the sound pressure levels at a given measurement point before and after the muffler is installed. The diagram of insertion loss measurement is shown in Figure 1. The mathematical expression of the insertion loss is as follow [5]:

$$ L_{IL} = L_{P1} - L_{P2} \cdot $$ (1)

Where, $ L_{P1} $ is the sound pressure level at the measuring point before the muffler is installed, and $ L_{P2} $ is the sound pressure level at the measuring point after the muffler is installed. The unit of insertion loss is dB.
In the measurement, the alternative pipeline is connected and $L_{p1}$ is obtained firstly. Then the alternative pipeline is replaced by the muffler to be measured, and $L_{p2}$ at the measuring point is obtained. The insertion loss of the muffler $t$ can be obtained by calculation based on Eq. (1).

![Diagram 1](image1.png)

Figure 1: The measurement diagram of the insertion loss

### 2.3 The measurement method of hydrodynamic noise

To get the sound pressure of hydrodynamic noise, hydrodynamic noise is measured at three points in the pipeline. The schematic diagram of the measurement system is shown in Figure 2.

![Diagram 2](image2.png)

Figure 2: The measurement diagram of the hydrodynamic noise

The integrated sound pressure at each point measured by the hydrophone at the frequency $f$ is the sum of the acoustic and pseudo-acoustic components. The acoustic components of the hydrodynamic noise in the pipeline at the points $n$, $m$, and $k$ can be obtained by the following formula. The relationships between the self-spectrum of the acoustic component at each measurement point and the correlation spectrum of the hydrodynamic noise recorded directly by the hydrophone at the measurement point are given as follow:

$$G_{p_n} = \frac{|G_{p_n}|}{|G_{p_n}|}, \quad G_{p_m} = \frac{|G_{p_m}|}{|G_{p_m}|}, \quad G_{p_k} = \frac{|G_{p_k}|}{|G_{p_k}|}. \quad (2)$$

Where, $G_{p_n}, G_{p_m}, G_{p_k}$ are the complex correlation spectra of the hydrodynamic noise recorded by the hydrophone installed at points $n$ and $m$, points $n$ and $k$, and points $m$ and $k$, respectively; $G_{p_n}, G_{p_m}, G_{p_k}$ are the self-spectrum of the hydrodynamic noise measured by the hydrophone installed at the points $n$, $m$, and $k$, respectively. $G_{p_n}, G_{p_m}, G_{p_k}$ are the acoustic components of the hydrodynamic noise measured by the hydrophone installed at the points $n$, $m$, and $k$, respectively.
The effective value of the acoustic component of the hydrodynamic noise at the measuring point can be obtained as follows:

\[ p_n = \sqrt{G_{p_n}}, \quad p_m = \sqrt{G_{p_m}}, \quad p_k = \sqrt{G_{p_k}}. \]  

(3)

3. The design of test bench

Set the inflation pressure in the bladder of the muffler \( P_a \), the working pressure of the piping system \( P_s \). Because the performance of the bladder type muffler is closely related to the inflation pressure \( P_a \) and the working pressure of the piping system \( P_s \), the test bench is designed with a pressure adjustment system to study the relationship between the performance of the muffler and \( P_a \), \( P_s \), where the system pressure \( P_s \) and the bladder inflation pressure \( P_a \) can be continuously and linearly adjusted. The diagram of the entire test bench system is shown in Figure 3 and the test site is shown in Figure 4.

The test system is equipped with a variable frequency pump to ensure the water flow in the pipeline and produce pulsating pressure and water noise. At the same time, the flow rate of the system can be changed from 50m\(^3\)/h to 100m\(^3\)/h by adjusting the motor speed by the inverter. The corresponding shaft frequency of the motor can be changed from 28Hz to 56Hz. At the same time, a water tank which can change the system pressure is set in the experimental bench, and the system pressure of the circulation pipeline is adjusted by the air compressor pressing the water tank. The system pressure \( P_s \) can be continuously and evenly changed in the range of 0 to 4 MPa.

![Figure 3: The measurement diagram of the experiment.](image1)

![Figure 4: The testing ground.](image2)
4. The test results under different conditions

The test is divided into 9 different cases. The muffler is used in Case1 to Case 9 and the alternative pipeline is used in Case9. In each case, the system flow rate is kept the same, while the inflation pressure in the bladder of the muffler $P_a$ is set in different fixed values. By continuously adjusting the pressure of the pipeline system $P_s$ in the given range, a fixed value $P_{sw}$ is obtained, under which the muffler gives the best performance. The law of the muffler performance as the system pressure $P_s$ changes can be obtained at the same time. The different values of $P_a$ and $P_s$ in each case are shown in Table 1.

<table>
<thead>
<tr>
<th>Category</th>
<th>The inflation pressure in the bladder of the muffler $P_a$ (MPa)</th>
<th>The variation range of $P_s$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>0.3</td>
<td>0.3—1.5 MPa</td>
</tr>
<tr>
<td>Case 2</td>
<td>0.5</td>
<td>0.3—2.0 MPa</td>
</tr>
<tr>
<td>Case 3</td>
<td>0.8</td>
<td>0.3—3.0 MPa</td>
</tr>
<tr>
<td>Case 4</td>
<td>1.0</td>
<td>0.3—3.0 MPa</td>
</tr>
<tr>
<td>Case 5</td>
<td>1.5</td>
<td>0.3—4.0 MPa</td>
</tr>
<tr>
<td>Case 6</td>
<td>2.0</td>
<td>0.3—4.0 MPa</td>
</tr>
<tr>
<td>Case 7</td>
<td>2.5</td>
<td>0.3—4.0 MPa</td>
</tr>
<tr>
<td>Case 8</td>
<td>3.0</td>
<td>0.3—4.0 MPa</td>
</tr>
<tr>
<td>Case 9</td>
<td>alternative pipeline</td>
<td>0.3—4.0 MPa</td>
</tr>
</tbody>
</table>

5. The results of the experiment

5.1 The change of the insertion loss with the change of $P_s$

To accurately find the pipe system pressure $P_{sw}$ under which the muffler gives the best performance of noise reduction, the pressure $P_s$ of the system is continuously adjusted from the minimum 0.3 to the maximum 4.0 MPa during the test as shown in Figure 5. At the same time, the hydrophone is continuously sampling so that the changing curves of the water noise levels $L_{P2}$ at the outlet of the muffler and the water noise levels $L_{P1}$ at the outlet of the alternative pipeline along with the change of system pressure $P_s$ are obtained, respectively. The insertion loss $L_{IL}$ of the muffler can be obtained according to Eq. (1).
From the above, when the inflation pressure $P_a$ is 0.3Mpa, 0.5Mpa, 0.8Mpa, 1.0Mpa, 1.5Mpa, 2.0Mpa, 2.5Mpa, 3.0Mpa, the variation of the insertion loss with the change of $P_s$ are shown in Fig.6 to Fig.13, respectively.
As can be seen from the figure, with the inflation pressure $P_a$ remains unchanged in each case, the insertion loss $L_{IL}$ of the muffler changes with the change of the system pressure $P_s$, and there is a peak in each case. When the system pressure $P_s$ is lower than the bladder inflation pressure $P_a$, the muffler basically has no effect; when the system pressure $P_s$ gradually increases and exceeds the inflation pressure $P_a$, the muffler starts to produce an anechoic effect and reaches a peak at the system pressure $P_{sw}$. When the system pressure $P_s$ continues to rise, the muffler’s noise reduction effect gradually weakens and finally remains stable.

To further analysis the Fig.6 to Fig.13, the relationship between the system pressure $P_{sw}$ under which the muffler gives the best performance and the inflation pressure $P_a$ can be obtained as shown in the following table.

<table>
<thead>
<tr>
<th>The pressure in the bladder of the muffler $P_a$ (MPa)</th>
<th>0.3</th>
<th>0.5</th>
<th>0.8</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>The system pressure $P_{sw}$ (MPa)</td>
<td>0.42</td>
<td>0.75</td>
<td>0.96</td>
<td>1.15</td>
<td>1.72</td>
<td>2.17</td>
<td>2.76</td>
<td>3.21</td>
</tr>
<tr>
<td>$\Delta P = P_{sw} - P_a$ (MPa)</td>
<td>0.12</td>
<td>0.25</td>
<td>0.16</td>
<td>0.15</td>
<td>0.22</td>
<td>0.17</td>
<td>0.26</td>
<td>0.21</td>
</tr>
<tr>
<td>$\eta = \frac{P_a}{P_{sw}}$</td>
<td>71.43%</td>
<td>66.67%</td>
<td>83.33%</td>
<td>86.96%</td>
<td>87.21%</td>
<td>92.17%</td>
<td>90.58%</td>
<td>93.46%</td>
</tr>
</tbody>
</table>

It can be seen from Table 2 that the difference $\Delta P$ between $P_{sw}$ and $P_a$ remains basically the same within a certain range. That is, when $P_a$ is higher than the bladder inflation pressure $P_a$ about 0.1 to 0.2 Mpa, the muffler provides the optimal performance. In contrast, if we want to get the best noise-reducing effect of the muffler, the inflation pressure in the bladder $P_a$ should slightly lower than the pressure in the piping system $P_s$, that is, $P_s - P_a$=0.1~0.2Mpa is required. At the same time, it can be seen from the table that the value of $\eta$ changes in a relatively large range. This means there is no absolute correlation between the optimal noise attenuation effect of the bladder muffler and the value of $P_a / P_{sw}$, which is different from the previous study [2].

### 5.2 The frequency domain analysis

To furtherly analyze the acoustic characteristics of the muffler in the frequency domain, the hydrodynamic noise level measured by the hydrophone at the inlet and the outlet of the muffler is subjected to FFT transformation analysis. It can be obtained under Case 1 and Case 2 as examples that the line spectrum of the water noise at its inlet and outlet is in the range of 20 Hz to 1000 Hz when the muffler has
the best performance as shown in Fig. 14 and Fig. 15. It can be seen from the figure that the bladder muffler has an abatement effect in the full range of 20 Hz to 1000 Hz, and it also has a good attenuation effect on the line spectrum at low frequency range.

![Figure 14](image1.png)  ![Figure 15](image2.png)

**Figure 14:** The line-spectra of the noise level at the inlet and outlet of the muffler ($P_s=0.3\text{Mpa}$, $P_i=0.42\text{Mpa}$).

**Figure 15:** The line-spectra of the noise level at the inlet and outlet of the muffler ($P_s=0.5\text{Mpa}$, $P_i=0.75\text{Mpa}$).

### 6. Conclusions

1. With the inflation pressure $P_a$ remains unchanged in each case, a fixed value $P_{sw}$ is obtained from the range of $P_s$, under which the muffler gives the best performance. For example, when the bladder inflation pressure $P_a=0.3\text{Mpa}$ and the pipeline system pressure $P_s=0.42\text{Mpa}$, the noise reduction performance of the muffler is optimal.

2. When the muffler bladder inflation pressure $P_a$ remains the same in each case, the effect of the muffler changes significantly as the system pressure $P_s$ changes. When $P_s < P_a$, the muffler basically has no effect. When the system pressure $P_s \geq P_a$, and satisfies $P_s - P_a \approx 0.1\sim0.2\text{Mpa}$, the muffler effect is optimal. When the system pressure $P_s$ continues to rise, the silencing effect of the muffler gradually start to weaken.

3. In each condition, as the pressure inflated in the muffler increases, the corresponding optimal effect of the muffler gradually decreases. That is, the noise reduction effect of the muffler decreases as the bladder inflation pressure increases.

4. The bladder type seawater muffler has a certain noise elimination effect in the frequency range of 20Hz~1kHz, and also it has a good attenuation effect on the line spectrum at the midline and low frequency domain.

### REFERENCES


