Study on Pressure Pulsation Suppression of Reciprocating Pump

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Abstract. The reciprocating pump has the problem of excessive pulsating pressure due to the inherent characteristics of the equipment, which causes the system to have large vibration and noise in the process of conveying fluid. Aiming at the problem of reciprocating pump pressure pulsation, the solution of reciprocating pump pressure pulsation suppression is put forward in this paper. The comparison test before and after the system improvement shows that the pulsating pressure inside the system has been significantly suppressed, and the pulsating abatement device adopted has a better application prospect.

1. Introduction
Reciprocating pump is often used to perform bilge discharge and other service tasks due to their excellent self-absorption performance. It has certain advantages for the medium conveying small flow and high head. However, due to the inherent discontinuous flow of the piston during the reciprocating movement, the discharge of the pump outlet is uneven, which causes the pressure pulsation of the system pipeline and makes the system inevitably impact and vibration during the fluid transportation. This may not only cause damage to the pipe and its accessories, but also transfer pipe vibration to the ship through various connectors, resulting in increased vibration and environmental noise of the ship. The piston in the first half of the stroke for acceleration, the latter half of the stroke for deceleration, its displacement is not uniform. Due to the inhomogeneity of instantaneous flow rate, the inertial force is generated by the variable acceleration of fluid in the pipeline. It is found that there are overturning moment, reciprocating inertia force and centrifugal force in the pump group. The unbalance force and fluid pulsation generated by these mechanical movements are the main reasons for the system to produce pressure pulsation.

2. Pressure suppression characteristics
The calculation principle model of the reciprocating pump system is shown in Fig. 1, where \( P \) stands for pressure pulsation, \( Q \) for flow pulsation, and \( Z_p \) for impedance of the pulsation abatement device. The following assumptions are made when calculating the model: the flow pulsation remains unchanged and the pressure pulsation changes after installing the device in the system. Pressure pulsation at the end of the system remains constant and \( P_0 \) is zero.
Figure 1. Pressure fluctuation model of the system

It can be obtained by the wave equation of the pipeline:

\[
\begin{pmatrix}
P_1 \\
Q_1
\end{pmatrix} = \begin{pmatrix}
\cos a \\
\sin a \\
\end{pmatrix} \begin{pmatrix}
jZ_c \\
\frac{1}{a}
\end{pmatrix} \begin{pmatrix}
P_0 \\
\frac{1}{Z_p}
\end{pmatrix} \begin{pmatrix}
P_0 \\
\frac{1}{Z_p}
\end{pmatrix}
\]

(1)

\[
\begin{pmatrix}
P_1 \\
Q_1
\end{pmatrix} = \begin{pmatrix}
\frac{1}{\cos a} \\
\sin a \\
\end{pmatrix} \begin{pmatrix}
\cos a \\
\sin a \\
\end{pmatrix} \begin{pmatrix}
P_0 \\
\frac{1}{Z_p}
\end{pmatrix} \begin{pmatrix}
P_0 \\
\frac{1}{Z_p}
\end{pmatrix}
\]

(2)

- \omega is the pulsating angular frequency;
- \( l \) is the length of pipe;
- \( a \) is the sound velocity in the fluid medium;
- \( Z_c \) is the characteristic impedance of the pipeline;
- \( \rho \) is the fluid density;
- \( A \) is the cross sectional area of the pipeline;
- \( Z_p \) is the impedance of the pulsating subduction device;
- \( K_v \) is the volume stiffness of the elastomer.

\[
P_1 = jZ_c \cdot Q_1 \cdot \tan \frac{a}{\omega}
\]

(3)

\[
P_1' = jZ_c \sin \frac{\omega}{a} \cdot Q_1
\]

(4)

The value of pulsation suppression:

\[
L_p = 20 \log \left| 1 - \frac{Z_c \omega \tan \frac{a}{\omega}}{K_v} \right|
\]

(5)

3. Numerical simulation of system

3.1 Device model

Aiming at the pressure pulsation mechanism of reciprocating pump, the pulsation abatement device can be installed in the system pipeline to suppress the amplitude of pressure pulsation inside the system. Select \( l \) is 250mm, \( L \) is 500mm, \( d \) is 50mm, \( D \) is 150mm.

Figure 2. Schematic structure diagram of pulsation abatement device
The grid size is set to 10mm, the absolute sag is set to 1mm, and the element type is selected as linear. The wave absorber is meshed as Fig 3. The results are as follows:

- 100.0% of the elements valid up to 3788.6Hz;
- 80.0% of the elements valid up to 4262.6Hz;
- 60.0% of the elements valid up to 4548.8Hz;
- 40.0% of the elements valid up to 4903.5Hz;
- 20.0% of the elements valid up to 5306.0Hz.

In order to guarantee the calculation accuracy, the calculation upper limit frequency should not exceed 3788.6Hz.

3.2 Simulation model

3.2.1 Parameter Settings

It is necessary to define a sound absorbing property on the outlet to simulate the non-reflecting boundary. Acoustic impedance of fluid is set as 416.5. The boundary type of outlet is impedance. The simulation frequency is from 10Hz to 3500Hz and the step length is 10Hz.

3.2.2 Sound pressure response

The lower side is the damper inlet and the upper side is the damper outlet, and the sound pressure response at the inlet and outlet of 10Hz to 3500Hz are analysed. The sound pressure response under typical frequency conditions is shown in the following figure.
Figure 4. Diagram of sound pressure response at inlet and outlet ends

It can be seen from Fig 4 that the pulsation abatement device has a good effect on the intermediate frequency about 350Hz to 1000Hz. The pressure level frequency response curve is shown in Fig 5.
3.2.3 Insertion loss

According to formula 5, the insertion loss of the pulsation abatement device is calculated. The calculation results are shown in the figure below.

4. Experiment

4.1 Experiment system

The test system is mainly composed of reciprocating pump, wave damper, ball valve, check valve and pressure sensor, which as shown in Fig 8 below.
Dynamic signal analyzer records the time-domain curve of pressure pulsation by pressure sensor, the frequency domain line spectrum can be obtained by FFT, and the total value of pressure pulsation within a certain frequency range is calculated by the formula below.

\[ P_l = jZ_e \cdot Q_1 \cdot \frac{\partial \phi}{\partial t} \]  \hspace{1cm} (6)

- \( n \) is the number of frequency;
- \( P_r \) is the reference pressure.

4.2 Experiment conditions
During the test, a section of rigid pipe is firstly installed in the test section, and the pressure pulsation value of the system is recorded with the dynamic signal analyzer. Then replace the rigid tube of the test section with the pulsation abatement device and repeat the above test. The difference of pressure pulsation value measured. The difference of pressure is the pulsation dampening effect of the pulsation abatement device.

\[ \Delta P_{pt} = P_{pt}^G - P_{pt}^L \]  \hspace{1cm} (7)

4.3 Experiment results
Fig 9 shows the time-domain comparison curve before and after the installation of the pulsating abatement device measured by the dynamic pressure sensor. It can be seen that the pulsating pressure amplitude of the system before installation can reach to 0.35MPa. After the installation of the pulsating abatement device, the system pulsating pressure is generally lower than 0.05MPa, and the dynamic pressure pulsation inside the installation system is significantly reduced.

The insertion loss in the frequency domain as shown in Fig 10 is obtained after processing according to formula 6 and formula 7. In the low frequency band below 600Hz, the pulsating abatement device has a relatively good effect on the pressure pulsation suppression of the system, generally above 15dB, which is mainly caused by the low-frequency pressure of the reciprocating pump.
It is known that the outlet pipe of the reciprocating pump system is 65mm, the crankshaft speed of the bilge pump is 170r/min, water sound speed is 1500m/s, and the elastic volume stiffness is about 1000MPa/m³. Pipe impedance is $4.52 \times 10^8$, pulse angular frequency is 70.9. Assuming the pipe length and substitute the above data into formula 7, the pressure pulsation suppression effect can be calculated as:

\[
L_{p=0.5} = 20 \log \left( \frac{4.52e8}{1000e6} \cdot \frac{22.6 \cdot \pi \cdot \log \frac{22.6 \times 5 \cdot \pi}{1500}} \right)
\]

(8)

In the range of 10Hz to 3.5kHz, the pressure pulsation of reciprocating pump system can be suppressed by installing pulsation abatement device. The pressure pulsation value of the system before installation is 98.2dB and after installation is 80.6dB, which can reduce the system pressure pulsation about 17.6dB and is basically consistent with the calculation results. The calculation result of insertion loss is 16.5dB.

5. Conclusions

The pressure pulsation of the system is caused by the inherent discontinuity of the reciprocating pump. In order to suppress the pressure pulsation of the system, this paper mainly works from several aspects. Firstly, the characteristics of internal pressure pulsation and its influencing factors are analysed, and the main technical scheme of the pressure pulsation suppression is determined. Secondly, according to the research plan, the simplified calculation model of the pressure pulsation of the system is established by using the pressure fluctuation equation of the pipeline system, and the suppression effect of pressure pulsation is preliminarily calculated. Thirdly, test verification is carried out for typical working conditions, and the test data are analysed. The research in this paper shows that the wave damper can significantly suppress the fluid pressure pulsation of the reciprocating pump and has a good application prospect.

According to add the pulsation abatement device to the reciprocating pump system can effectively suppress the pulsating pressure in the process of reciprocating pump operation. According to the working frequency of the pump set, the pressure pulsation of the system is effectively reduced, the pressure of the system is stabilized, and the vibration and noise of the system are effectively reduced.

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