Research of Pressure Fluctuation with Experiment and Numerical Simulation for Dredging Pump

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Abstract. In order to reveal the dredge pump flow instability characteristics, the cavitation and pressure fluctuation in experimental study are carried out, the pressure fluctuation frequency domain and time domain characteristics of three different position inside the volute are analyzed. The results showed that, before cavitation, the main frequency at different positions at different flow rates is 1 times the main frequency of the blade. The fluctuation amplitude near the volute tongue and diffusion section is slightly larger than that at other positions. Before cavitation, the fluctuation amplitude at the same position off design flow is slightly higher than that near the design flow. Cavitation has little influence on the main frequency of the pressure fluctuation. After cavitation, the pressure fluctuation amplitude in the low flow point and the position of the volute tongue under each condition has little change, but cavitation aggravates the pressure fluctuation in the other conditions. Besides, the comparison between simulation and experiment results shows the dredge pump performance curve is in good agreement with the simulation curve, and the simulation results of pressure amplitude at different positions are basically consistent with the experiment results, which verifies the reliability of the numerical simulation method.

Keywords. Dredge pump, pressure fluctuation, experiment, numerical simulation.

1. Introduction
Dredger pump is one of the key transport equipment of dredging engineering ships such as trailing suction dredger and cutter suction dredger. Its operation stability has a very important impact on the dredging efficiency of dredging ships. The dredge pump is mainly a centrifugal dredge pump. The dynamic and static interference between the impeller and the volute makes the pressure in the pump change with time and form pressure pulsation. The flow instability caused by cavitation of dredge pump and off design operation of dredge pump will aggravate the pressure fluctuation. The larger pressure fluctuation may further aggravate the generation of local cavitation, or even cause resonance [1-2], which has a direct impact on both the stability of the dredger's own structure and the dredging efficiency. Therefore, it is of great significance to study the pressure fluctuation characteristics of dredge pump for improving the operation stability and dredging efficiency of dredge pump.

At present, many numerical simulation and experimental studies have been carried out on the pressure fluctuation in centrifugal pump by domestic and foreign scholars. the pressure fluctuation in different positions of the volute is monitored through the test by Parrondo [3], it shows that the dynamic and static interference between the impeller volute plays a key role in the pressure fluctuation; A centrifugal pump with low specific speed is used to study the vibration and pressure fluctuation by Gao [4], and the results indicate that the pressure fluctuation signal and the pump body vibration
signal have strong coherence at each basic frequency, and Gao thinks the main reason of low frequency vibration of centrifugal pump is the interference of dynamic and static in centrifugal pump and unbalance of rotor; Yuan [5] analyzed the pressure fluctuation of impeller and volute under the design condition by numerical simulation, it is found that the main frequency of fluctuation is similar to that of blade, and the high frequency part mainly occurred in impeller channel, and no high frequency fluctuation is observed in the volute; Yang [6] takes double-walled dredge pump as the research object, he calculates and analyzes the pressure fluctuation characteristics under unsteady cavitation state, it is found that the main frequency of pressure fluctuation in the circumferential direction of the volute is blade frequency, the cross-section area of the volute has a great influence on the pressure fluctuation, and the pressure fluctuation at the tongue is affected by cavitation flow; Hui [7] monitor the pressure fluctuation in the impeller and volute channel by numerical calculation, it was found that the pressure fluctuation of centrifugal pump was higher under the condition of small flow. Besides, the pressure fluctuation at the volute tongue and outlet was obvious due to vortex and backflow under the condition of large flow.

Although domestic and foreign scholars have done a lot of research on the pressure fluctuation of centrifugal pump and achieved some results, there are still few experimental studies on the pressure fluctuation of centrifugal pump after cavitation, and there are some differences in the flow characteristics of different series of dredge pumps. Therefore, this paper conducted an experimental study on the pressure fluctuation of a dredged mud pump before and after cavitation. By monitoring the pressure fluctuation of the volute section, the time domain and frequency domain characteristics of the pressure at the test position were analyzed to reveal the variation law of the pressure fluctuation before and after cavitation. Considering the long test period and high cost, the numerical simulation of pressure fluctuation before cavitation was carried out, and the accuracy of the numerical method was verified by comparing the experiment results, so as to provide a certain basis for the subsequent analysis of the flow instability characteristics of different types of dredge pumps.

2. Parameters and Structure of Dredge Pump
The dredge pump parameters are as follows: impeller type is centrifugal impeller, suction diameter is 350mm, impeller diameter is 910mm, design flow is 1800m³/h, design head is 45m, impeller speed is 600rpm, blade number is 4, discharge diameter is 250mm. The dredge pump structure includes impeller, volute, front and rear wearing liner, etc. in order to simplify the structure, the pump is not equipped with water sealing structure, as shown in figure 1.

![Figure 1. structure of dredge pump.](image)

3. Experiment Method
The experiment accuracy reaches the level 1 accuracy requirements of GB / T 3216-2016. In this test, the motor speed is 1500 rpm, and the pump speed is 611-613 RPM through the reducer. The position of pressure fluctuation test point including M1, M2 and M3 is shown in figure 2.
Figure 2. Experiment system and position of pressure fluctuation sensor.

The instruments used in the experiment, such as vacuum sensor, discharge pressure sensor and flowmeter, have been calibrated and qualified. The torque sensor model is JC3a-1000, equipped with secondary instrument which can output 4-20mA signal. The pressure fluctuation sensor is connected with a data collector. Its model is ws-5931u160216c16. The sampling frequency is 2000 Hz, and the sampling time of each test point is 10 s. The measured flow range is 600 ~ 2600 m$^3$/h. The pressure fluctuation and cavitation test points include five flow points: 600 m$^3$/h, 1000 m$^3$/h, 1400 m$^3$/h, 1800 m$^3$/h and 2200 m$^3$/h. In the cavitation experiment, the inlet pressure is continuously reduced by adjusting the inlet pipeline valve, and the head drop of 5% is taken as the evaluation standard of cavitation at the corresponding flow point. It should be noted that:

- The pipe resistance between pressure measuring points should be considered in head calculation, and the experiment data should be corrected in data analysis.
- The installation height of the vacuum sensor and the discharge pressure sensor is the same; The influence of different pipe diameters on the velocity head has been considered in the experiment system, so the velocity head will not be calculated in data processing.
- The torque sensor and the pump shaft are connected by a pair of elastic pin couplings, and the coupling efficiency should be considered in the calculation of pump power.
- All experiment data are converted to 600 rpm based on Similarity Laws.

4. Experiment Results

Taking the impeller rotating 2 times as the time axis, the amplitude is the difference between the instantaneous pressure and the average pressure. Figure 3 is the time domain diagram of the test pressure fluctuation before and after cavitation at the design flow rate (1800 m$^3$/h). It can be seen from the diagram that the pressure fluctuation changes periodically before cavitation. Before cavitation, the fluctuation amplitude at M1 is greater than at M2, and the fluctuation amplitude at M2 is greater than at M3. The reason is that M1 is affected by the interference between impeller and volute tongue, so the fluid flow is more complex. M2 is close to the diffusion section of volute, so the flow field is also unstable. While M3 is far away from the outlet of volute tongue and diffusion, so the flow at M3 is relatively stable; Compared with before cavitation, cavitation has little effect on the amplitude of pressure fluctuation at M1 and M3. But the maximum amplitude of pressure fluctuation at M2 after cavitation is about twice that before cavitation, which indicates that a large number of cavitation bubbles formed by cavitation flow to the volute outlet under the action of impeller rotation, which intensifies the pressure fluctuation near M2. Fourier transform the above experiment results to obtain the frequency domain diagram of pressure fluctuation, as shown in figure 4, where fn (10Hz ) is the rotation frequency of the impeller, and the number of blades is 4. Therefore, the dominant frequency of blades (referred to as blade frequency) is 40 Hz. It can be seen that the pressure fluctuation frequency of each measuring point is mainly blade frequency, and the secondary main frequency is twice blade frequency; Before and after cavitation, the position of the main frequency of the pressure fluctuation remains unchanged, and the main frequency and the secondary frequency are still 1 and 2 times of the blade frequency respectively.
Figure 3. Time domain at design point before and after cavitation. (a), (b), (c) represent the position of M1, M2, M3 respectively.

Figure 4. Frequency domain at design point before and after cavitation.
Figure 5 and figure 6 show the frequency domain experiment results of pressure fluctuation at M1, M2 and M3 before and after cavitation at five flow points of 600 m$^3$/h, 1000 m$^3$/h, 1400 m$^3$/h, 1800 m$^3$/h and 2200 m$^3$/h respectively. It can be seen that the main frequency of pressure fluctuation at all measuring flow points before and after cavitation is blade frequency; Before cavitation, the maximum amplitude of fluctuation is larger at the flow rate of 600 m$^3$/h, and there is little difference between different test positions, which indicates that the whole flow in the dredge pump is extremely unstable at low flow rate, while at other measuring flow points, the maximum amplitude of fluctuation is larger at M1 position with the same flow rate, which indicates that the dynamic and static interference of impeller and volute has the greatest impact on pulsation at this time. The fluctuation amplitude at M2 and M3 is relatively low; Compared with that before cavitation, cavitation has little influence on the maximum amplitude of pulsation at each position when the flow rate is 600 m$^3$/h, which indicates that cavitation has little influence on the flow field in the pump, the main reason is that the flow points is far from the design flow rate, the flow in the pump is very complex, and the fluctuation amplitude is larger than other conditions, at this time, the cavitation is hardly to affect the flow field. In addition, compared with that before cavitation, M1 is the least affected by cavitation, and the distribution of fluctuation amplitude is the same as that before cavitation. M2 is the most affected by cavitation at 1800 m$^3$/h and 2200 m$^3$/h. Different from M2, M3 is far away from the volute outlet, and the fluctuation amplitude is weakened at the flow rate of 2200 m$^3$/h, This shows that the cavitation aggravates the backflow and flow instability in the diffusion section of the volute when the flow rate is large.

![Figure 5](image1.png)

![Figure 6](image2.png)
5. Comparison between Simulation and Experiment

In dredging engineering, different models of dredgers are equipped with different dredge pumps, and the flow characteristics of different dredge pumps are quite different. Considering that the experiment itself requires a long period and the experiment conditions are more complex, therefore, the numerical simulation of pressure fluctuation before cavitation of dredge pump is further carried out, which can provide a certain basis for the subsequent analysis of the flow characteristics of different dredge pumps.

5.1. Numerical Simulation

The numerical simulation is carried out based on ANSYS CFX 19.2. The computation model includes impeller, volute and inlet and outlet extension, as shown in figure 7. The unstructured tetrahedral grid is used as the calculation grid. Through the grid independence at the design point, the final grid is 2 million. The normal speed and opening are taken as the boundary of inlet and outlet respectively. The rotating reference coordinate is used for the moving surface of impeller; Volute wall adopts no slip wall; The convergence accuracy is set to 1E-4; Considering that the SST model is more accurate for the prediction of flow separation [8], the SST model is selected as the turbulence model for numerical calculation.
5.2. Energy Performance

Figure 8 shows the energy performance comparison between the simulation and the experiment results of the dredge pump. It can be seen that the performance curves of the simulation and the experiment are generally in good agreement. The efficiency curve of the dredge pump is flat and the high efficiency area is wide. The simulated head value and efficiency are slightly higher than the experimental value. At the design flow point of 1800 m³/h, the simulation head is 46.3 m, and the simulation efficiency is 87%, which is 0.8 m higher than the experiment head and 3 percentage points higher than the experiment efficiency. The above analysis shows that the numerical model and experimental results can well reflect the energy performance of the dredge pump, which provides a strong support for further analysis of the pressure fluctuation.

5.3. Pressure Fluctuation

Figure 9 is comparison of the time domain diagram of pressure fluctuation at M1, M2 and M3 before cavitation at design flow point between experiment and simulation. It can be seen from the picture that the simulation results of pressure fluctuation amplitude at different positions are basically consistent with the experiment results. Figure 10 shows the frequency domain diagram of pressure fluctuation at M1, M2 and M3 before cavitation at design flow rate. It can be seen that the simulation results are consistent with the experiment results. The pressure fluctuation frequency of each measuring flow point is mainly blade frequency, and the secondary main frequency is twice blade frequency; In the main frequency part, the simulated amplitudes of M1 and M3 are basically consistent with the experimental results, and the simulated fluctuation amplitudes of M2 are slightly larger than the experimental values, about 1.5 times of the experimental values; In addition, only the water part of the pump is calculated and analyzed, and the whole system of the pump is not calculated, so the high frequency part is not predicted in the simulation.
Figure 9. Pressure fluctuation time domain at design flow point.

Figure 10. Pressure fluctuation frequency domain at design point.
6. Conclusion
Through the experiment and numerical simulation on the pressure fluctuation of a dredge pump, we can draw the following conclusions:

- Before cavitation, the pressure fluctuation amplitude near the volute tongue is larger than that of the volute diffusion section, and the pressure fluctuation amplitude far away from the tongue and outlet is the smallest; At the same position, there is no significant difference in the amplitude of pressure fluctuation under design flow point, and the amplitude of pressure fluctuation is larger under small flow and large flow.
- Before and after cavitation, the main frequency of pressure fluctuation remains unchanged, which is blade frequency; Under the design flow and large flow point, cavitation has a great influence on the maximum amplitude of pressure fluctuation at the diffusion section of the volute, which is about twice and four times of the maximum amplitude before cavitation respectively, but has little influence on other positions; Under the low flow point, there is no obvious change in the pressure fluctuation characteristics before and after cavitation, and different positions have little effect on the maximum amplitude of the pressure fluctuation.
- The simulation results of pressure fluctuation amplitude at different positions are basically consistent with the experiment results, and the main frequency position of pressure fluctuation at each measuring point is consistent, which verifies the reliability of the numerical method.

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