Experimental study on pressure fluctuation characteristics of model pump in HuangJinXia hydro-junction

Peng Dong
HanJiang-To-WeiHe River Valley Water Diversion Project Construction Co.Ltd., Shaanxi Province, Xi'an, 710100, China
E-mail: wuyajun@hwrwvd.cn; Telephone number: 15249224366

Abstract: In this study, the pressure pulsation characteristics of different position in the model pump unit are studied by experiments in combination with the HuangJinXia hydro-junction. The pressure pulsation of the inlet pipe, the volute outlet and the area between impeller and guide vane under different operating conditions were measured and analyzed. The results show that the maximum pressure pulsation amplitude of the pump is less than the guaranteed values by comparing the test results with the value requirement of the pump, which ensures the safe and stable operation of the pump. FFT transform is used to analyze the main frequency and amplitude of pressure pulsation. The main frequency and secondary frequency at the impeller inlet are respectively 15.29 and 7.65 times of the rotating frequency, which are 2 and 1 times of the blade frequency. The amplitude of main frequency at each monitoring point increases with the increase of head. The test results of pressure pulsation value meet the requirements of the contract in the whole pump operation rang.

1. Introduction
The internal flow field of the centrifugal pump is complex, cavitation will affect the pump pressure pulsation, the reliability of the pump operation is reduced [1]. Domestic and abroad scholars have done a lot of research on the unsteady flow characteristics and pressure pulsation in centrifugal pump under cavitation condition [2-4]. The pressure pulsation has been specified in detail in the pump design of large pump stations in China. Therefore, it is necessary to obtain the internal pressure pulsation parameters of the pump through model test and analyze its influence on the pump.

The process of cavitation is unsteady and will produce large pressure pulsation. If the pressure pulsation frequency is consistent with the natural frequency of the pump, the resonance of the whole unit may be caused, and great shock and noise will be generated, leading to a significant decline in the performance of the unit. Therefore, it is necessary to study the performance of cavitation and pressure pulsation [5]. Li et al. [6] carried out numerical calculation of full-channel unsteady cavitation flow in a pump turbine model, and concluded that with the change of cavitation coefficient, the frequency component at each position was almost unchanged, but the amplitude changed greatly. Wang [7] studied the variation laws of flow field characteristics and pressure pulsation in different cavitation moment of a high specific speed centrifugal pump through high-speed photography test and numerical simulation. Wang et al. [8] combined experiments with simulation to study the influence of cavitation on pressure pulsation of the low specific speed centrifugal pump. Cavitation reduces the power capacity of the impeller and results in the decrease of the inlet pressure pulsation frequency amplitude. Wang et al. [9] conducted an experimental study on typical cloud cavitation flows through multi-field synchronous test...
method. Li \cite{10} analyzed the pressure pulsation of the impeller and the volute monitoring point for different flow conditions.

In this paper, the pressure pulsation characteristics of the model pump unit are studied by experiments in combination with the pumping station project of HuangJinXia hydro-junction. The pressure pulsation of the inlet pipe, impeller inlet and the volute outlet under different conditions were measured and analyzed.

2. Introduction of the model pump test platform

In this study, a high-precision universal hydraulic test platform is used, and all the test parameters meet the related standards requirements of GB15613-2008, IEC. The original test equipment of the test bed is regularly tested by the state and authoritative testing department, and the relevant inspection department issues the testing certificate within the validity period, so as to meet the requirements of the measurement accuracy and operation stability of various test parameters of all the experimental items.

Table 1: Main parameters of the test platform

| Designations                  | Parameters |
|------------------------------|------------|
| Maximum test head            | 150 (m)    |
| Maximum discharge            | 2.0 (m³/s) |
| Impeller diameter            | 300~500 (mm) |
| Power of dynamometer         | 500 (kW)   |
| Dynamometer speed            | 0~2500 (r/min) |
| Pump motor power             | 600kW×2    |
| Flow correction cylinder volume | 120×2 (m³) |
| Reservoir volume             | 750 (m³)   |
| Comprehensive efficiency error | ≤±0.20%   |

Before the model test, the sensor for measuring each parameter was calibrated. The test bed is a closed circulation system, and the whole system can operate in both directions. The overall panorama of the test bed and the experimental system schematic diagram are shown in Figure 1 and Figure 2. The main components of the system include: water supply pump, water tank, model device, dynamometer motor, electromagnetic flowmeter, vacuum tank, tail tank, flow correction cylinder, electric valve, etc. The main parameters of the experimental platform are shown in Table 1.

The model pump is installed between the pressure tank and the tail tank, and the shaft of the model pump is connected with the dynamometer motor. The system flow rate is extracted from the reservoir by the water supply pump and supplied to the test equipment. The flow rate can be adjusted through the electric valve. The flow rate is measured by the bidirectional mass flowmeter with the accuracy of ±0.15% and the range of 0~0.8m³/s. The head is measured by 3051-CD4A-22A1A type differential pressure
sensor with an accuracy of 0.075% and a measuring range of 0–0.8MPa. The torque is measured by indirect measurement method and the rotation speed is measured by magneto electric speed sensor. All measured parameters in the test are collected and recorded through the centralized acquisition system.

3. Experimental requirements and contents

The pressure pulsation measurement is carried out in the whole operating range of pump and under the device’s NPSH allowance. According to the requirements, pressure measuring points are arranged at different parts of the pump device. Including, two measuring points are arranged in the inlet pipe conical section. There are four pressure pulsation measuring points from the impeller outlet to the guide vane blade inlet area. A measuring point of the volute outlet is arranged at the downstream side of the volute. In the test, measure and record the pressure pulsation double amplitude and frequency; pressure pulsation should be measured and analyzed by computer. Results using \( \frac{\Delta H}{H} \) form expression, \( \Delta H \) is the full amplitude between the peaks values in the mixing state of the measuring points, \( H \) is the corresponding head. The cavitation reference surface for pressure pulsation measurement is the central plane of guide vane. Pressure pulsation tests were carried out at 12 working points with \( H_p=94\text{m}–119\text{m} \). And the main frequency and pressure pulsation amplitude were analyzed by FFT (Fast Fourier Transform).

4. Pressure fluctuation experimental results and analysis

In order to fully reflect the variation of pressure pulsation in the pump device various places, the pressure pulsation in the pump was tested and measured at different heads and operating areas and the maximum pressure pulsation amplitude at each working condition in the test was shown in Table 2. The test results were compared with the guaranteed value requirements of the design and the pumping station device. The results show that the maximum pressure pulsation amplitude of the pump is less than the guaranteed value requirements, which ensures the safe and stable operation of the pump.

| Measuring point position | Operation conditions          | Experimental value (%) | Guarantee value (%) |
|-------------------------|-------------------------------|------------------------|---------------------|
| Inlet pipe              | Maximum head                  | 0.62                   | ≤5                  |
|                         | Design head                   | 0.53                   | ≤3                  |
|                         | Minimum head                  | 0.6                    | ≤5                  |
| Between impeller and    | Optimum operating condition   | 3.23                   | ≤5                  |
| guide vane              | Entire operating area         | 3.8                    | ≤8                  |
| Volute outlet           | Entire operating area         | 1.3                    | -                   |

Figure 3, Figure 4 and Figure 5 respectively show the variation law of pressure pulsation amplitude in different flow components of the pump with head. As can be seen from Figure 3, in the impeller outlet to guide vane inlet area, the pressure pulsation variation trend at each measurement point is similar, and the pressure pulsation decreases with the increase of head. Under the designed head, the pressure pulsation amplitude at each monitoring point is consistent and less than the guaranteed value. It can be seen from Figure 4 that the pressure pulsation at the volute outlet gradually decreases with the decrease of head. In Figure 5, the pressure pulsation amplitudes remain basically unchanged under each condition, which are all less than the guaranteed value. To sum up, the pressure pulsation test results at each measuring point of the pump meet the requirement of guaranteed value within the pump entire operation range.
Figure 3. Experimental results of pressure pulsation between impeller and guide vane

Figure 4. Experimental results of pressure pulsation at the volute outlet

Figure 5. Experimental results of pressure pulsation at the inlet pipe

Figure 6 shows the time domain and frequency domain variations of pressure pulsation at each monitoring point in the pump under four different head conditions. As can be seen from the figure, the variation trend of pressure pulsation in the pump is diverse at different heads. With the head increasing, the main frequency amplitude of pressure pulsation in different position increases continuously. The
main frequency of pressure pulsation at the impeller inlet is 254.88Hz and the secondary frequency is 127.44Hz. In the vane-less area, the dominant frequency is 382.45Hz and the secondary frequency is 254.88Hz, which is mainly caused by the interaction between impeller rotation and guide vane. The main frequency of pressure pulsation at the volute outlet is so low that can be ignored. All the main frequency amplitudes of pressure pulsation are less than the guaranteed value.

Hm=26.867m n11=50.32r/min Q11=0.6169m³/s
nM=849.65r/min fn=14.16Hz

Hm=25.305m n11=51.88r/min Q11=0.6830m³/s
nM=850.02r/min fn=14.17Hz

| Head | Frequency | Amplitude |
|------|-----------|-----------|
| 26.867m | f1=0.37Hz, f2=0.85Hz | ∆H/Hm=1.20% |
| 25.305m | f1=254.88Hz, f2=127.44Hz | ∆H/Hm=2.59% |

Figure 6. Time domain and frequency domain analysis of pressure pulsation under different heads

5. Conclusions
In this paper, based on the high-precision test platform and measuring elements, the pressure pulsation in the model centrifugal pump device is measured and studied, and the variation law of the pressure pulsation inside the pump under different heads is analyzed. The main conclusions are as follows:

1) By comparing the experimental results with the guaranteed value requirements of the pump station, the maximum pressure pulsation amplitude of each position in the pump is less than the guaranteed value requirements, which ensures the safe and stable operation of the pump.

2) FFT transform is used to analyze the main frequency and amplitude of pressure pulsation. In the test, the pump rotation frequency is 16.67Hz, and at the impeller inlet, the main and secondary frequency is 15.29 and 7.65 times of the rotation frequency respectively, which are two and one times of the blade
frequency. The amplitude of main frequency at each monitoring point increases with the increase of head.

(3) After the full working condition test, the test results of pressure pulsation value in A1515 model pump meet the requirements of the contract in the whole normal operating range.

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