

PAPER • OPEN ACCESS

Influence of the inlet vortex on axial flow pump unit

To cite this article: Xijie Song *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **240** 032005

View the [article online](#) for updates and enhancements.

Influence of the inlet vortex on axial flow pump unit

Xijie Song , Chao Liu , Fan Yang

School of Hydraulic Energy and Power Engineering, Yangzhou University, China

Email: 1227321904@qq.com

Abstract: Starting from the view on the influence of inlet vortex on the pressure pulsation in axial flow pump, the influence mechanism of inlet vortex on axial flow pump was investigated by the pressure fluctuation test. The pressure pulsation sensors are installed at the impeller inlet and the impeller outlet and the guide vane outlet. The pressure fluctuation test was carried out and the development process of the inlet vortex was clearly captured by the high speed camera. The results show that the amplitude of pressure pulsation under the small flow rate conditions is the largest at the same position of axial flow pump, and the amplitude of the pressure pulsation decreases gradually with the increase of flow rate. With the accumulation of rotational energy increasing more than dissipation and the suitable space and sufficient time, the inlet vortex occurs in the pump sump. The pressure pulsation excitation source in impeller inlet is the rotation of the impeller. And the pressure pulsation in the impeller inlet is influenced by the vortex. The pressure pulsation in the impeller outlet is induced by the rotor-stator interaction between the guide vane and the impeller. The pressure pulsation in the vane outlet is mainly influenced by the outlet circulation. Under the large flow rate conditions, the inlet vortex developed into the impeller, increasing the instability of the flow field inside the impeller and affecting the pressure pulsation interior the impeller, decreasing the unit vibration and hydraulic performance, causing the vibration of the pump unit.

1. Introduction

Because of the complex operating conditions of the axial flow pump, the safe operation of the axial flow pump has always been the focus of attention. The main factors affecting the safety and stability of the pump unit include the cavitation performance of the pump, the vibration of the pump unit, the pressure fluctuation of the pipeline and the abnormal noise of the pump unit. The three dimensional unsteady numerical simulation of the axial flow pump was analysed by Tang Fangping[1], that shows the amplitude of the pressure fluctuation at the pump impeller inlet under the small flow rate conditions and the large flow rate conditions is larger than that under the optimal operating condition. Liu[2] analyses the energy characteristics and pressure pulsation of the mixed flow pumps under different blade tip clearance, obtains that the tip clearance and the inlet pre whirl of the guide vane have important influence on the energy performance and pressure pulsation of the pump.

In recent years, with the rapid development of the CFD technology [3-5], the numerical simulation technology has been widely applied to this field. However, due to the limitation of



numerical simulation technology, numerical simulation results often lead to large deviations in the presence of complex swirling motion. In order to solve this problem, in this paper, the influence of the inlet vortex on the pressure pulsation is investigated by the pressure pulsation characteristics test [6-9].

2. Experiment apparatus

The energy performance experiment and the pressure fluctuation experiment of the vertical axial-flow pump were carried out on the axial flow pump experiment bench. The impeller diameter is 120mm, the blade tip clearance is 0.1mm, the hub diameter is 48mm, the number of the impeller blades is 4, and the number of the guide vanes is 7. The whole experiment bench is composed of open type pump sump, ISW150-200A stainless steel centrifugal pump, PVC pipe, constant pressure cylindrical water tank, stainless steel soft sealing butterfly valve, as shown in figure 1. The principle of this paper is from the point view of the influence of the inlet vortex on the internal pressure disturbance of axial flow pump flow field, to explore the influence of the pressure pulsation induced by the inlet vortex on the safe operation of the axial flow pump unit. So the pressure pulsation sensors were installed at the axial flow pump impeller inlet, impeller outlet and the guide vane outlet. The measuring point area and the specific position are shown in figure 2.



Figure 1. Axial flow pump experiment bench.

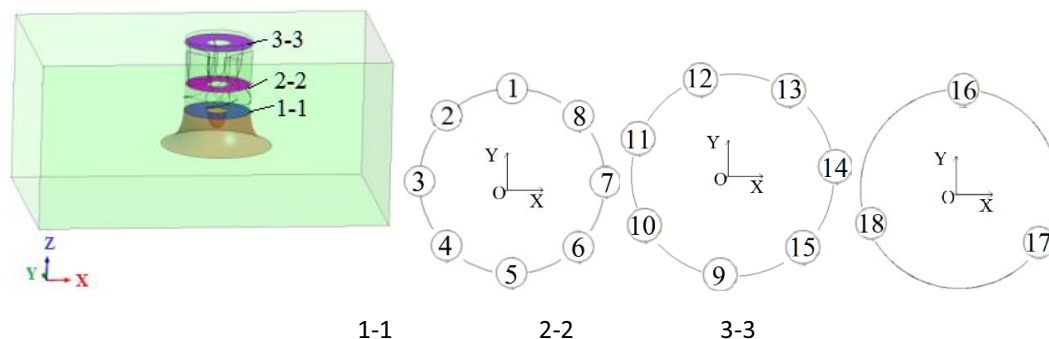


Figure 2. Position of the pressure pulsation measuring points.

In pressure fluctuation experiment, the pressure fluctuation sensor developed by Chengdu experiment is in the range of 0~60MPa, the experiment precision is 0.1%, the sampling time interval is 1ms~1s. The purpose of this experiment is to study the pressure fluctuation characteristics of water flow at the bottom of the pump sump and to explore the relationship between the vortex and the pressure distribution. Through observation, it was found that when the water depth of the pump sump was 300mm, the vortex production was the most obvious, so the water depth of the experiment scheme was 300mm. The experiment on the pressure fluctuation was conducted at 3 different operating condition points that is $0.8Q_d$, Q_d and $1.2Q_d$ respectively (Q_d is the design condition point) and at the speed of 2200r/min.

3. Experiment results and analysis

Three typical flow rate conditions at speeds of 2200 r/min were selected: $0.8Q_d$, Q_d and $1.2Q_d$ ($Q_d=32\text{L/s}$ design flow rate conditions). In the surface of the pump sump, the surface vortex occurred easily, so the cover plate was installed to eliminate the interference caused by the surface vortex. Due to the instability of the inlet vortex, in order to accurately measure the pressure change

when the vortex occurs, the sampling time t is 3s, and the sampling interval t_s is 1ms, that is, the sampling frequency is 1000 Hz.

The inlet vortex is easy to occur under the large flow rate conditions, and that is not easy to occur under the small flow rate conditions and design flow rate conditions. As shown in figure 3, the inlet vortex was captured by the high-speed camera under the large flow rate conditions. The inlet vortex is very sensitive to the flow boundary condition and the shape changes instantly. Due to the instability of the flow field, the inlet vortex partially or completely ruptured in the impeller inlet.

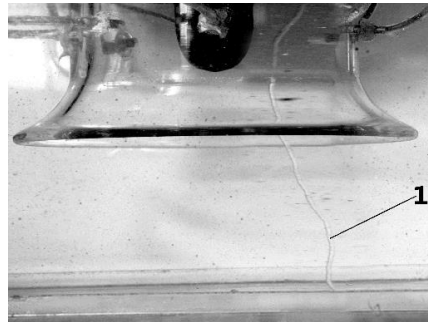


Figure 3. The inlet vortex in the pump sump.
1 vortex tube

3.1 Analysis of the time domain characteristics of the pressure fluctuation

Under different flow rate conditions, the characteristic points on each pressure pulsation monitoring surface were selected to analyze the time domain characteristics of pressure pulsation according to the position where the inlet vortex occurred, as shown in figure 4~6.

In order to better analyze the time domain characteristics of the pressure fluctuation, the dimensionless pressure fluctuation coefficient is introduced [10-12]:

$$C_p = (p - \bar{p}) / (\rho U_{tip}^2 / 2) \quad (3)$$

where p —instantaneous pressure of each monitor point, kPa

$\bar{p}$ —averaged pressure of each monitor point, kPa

ρ —the density of water, kg/m³

U_{tip} —circumferential velocity at the blade tip, m/s

$$U_{tip} = \frac{2\pi rn}{60}$$

Defines the period of rotation of the impeller:

where t —the acquisition time at any point

T —The time of the impeller rotates a circle

In this paper, the pressure fluctuation data of 5 impeller rotating cycles are analyzed

At the pump impeller inlet

The time domain characteristic curve of the pressure pulsation in the impeller inlet of the axial flow pump under different flow rate conditions are shown in figure 4. It can be seen from figure 4 (a) (b) (c) that the pressure in impeller inlet varies periodically under different flow rate conditions, and there are 4 peaks and 4 troughs in each pressure variation period. This indicates that the pressure change in the impeller inlet is mainly caused by the impeller rotation. The peak to peak

values of the pressure pulsation in the impeller inlet under the small flow rate conditions and the design flow rate conditions and the large flow rate conditions respectively reach 0.081, 0.073 and 0.068, as shown in figure 4 (a) (b) (c). Under the small flow rate conditions, the peak to peak value of the time domain curve of pressure pulsation at the impeller inlet changes the most at different time, and the shape of the curve is the worst. This is because the axial velocity of the flow is small under the small flow rate conditions and the viscous force and the boundary factors of the flow have a great interference influence on the flow. With a large amount of energy dissipation, there occurs the turbulent flow at the impeller inlet. With the increase of the flow rate, the peak to peak value of the time domain curve of pressure pulsation gradually decrease and the shape of the curve tend to be regular. This is because the axial velocity at the impeller inlet is large under the large flow rate conditions, the influence of the viscous force and the surrounding boundary factors on the flow are small, and the flow pattern is relatively stable.

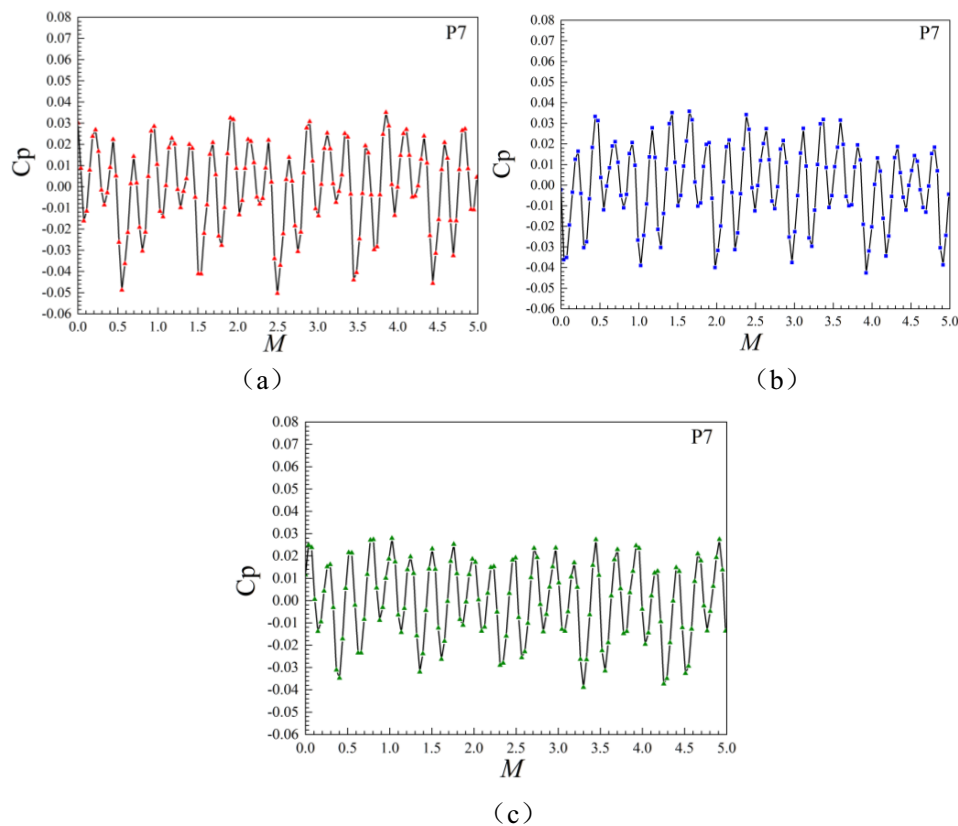


Figure 4. Time - domain diagram of monitoring points at the impeller inlet.

(a) $0.8Q_d$ (b) Q_d (c) $1.2Q_d$

At the pump impeller outlet

The time domain characteristic curve of the pressure pulsation in the impeller outlet of the axial flow pump under different flow rate conditions are shown in figure 5. The pressure pulsation at the impeller outlet is more chaotic than that at the impeller inlet, which is due to the rotor-stator interaction between the impeller and the guide vane at the impeller outlet. Under the small flow rate conditions, the peak to peak value of the time domain curve of pressure pulsation at the impeller inlet changes the most at different time, relative to the rotating impeller, the static guide blade as an exciting source will generate periodic excitation on the flow of the impeller outlet. Under the small flow rate conditions, the peak to peak value of the time domain curve of the pressure pulsation at the outlet fluctuate the most. The peak to peak value of the pressure fluctuation at the impeller outlet is 0.137 with 2 peaks and 2 troughs in one impeller rotation period under the small flow rate conditions, as shown in figure 5(a). With the increase of the flow rate, the peak to

peak value of the time domain curve of pressure pulsation gradually decrease and the shape of the time domain curve tends to be regular under the design flow rate conditions. The peak to peak value of the pressure fluctuation at the impeller outlet is 0.081 with 2 peaks and 2 troughs in one impeller rotation period under the design flow rate conditions, as shown in figure 5(b). Under the large flow rate conditions, the peak to peak value is the smallest and the curve shape is the worst. The peak to peak value of the pressure fluctuation at impeller outlet is 0.060, and the variation of pressure fluctuation is different in different impeller rotation periods under the large flow rate conditions, as shown in figure 5(c).

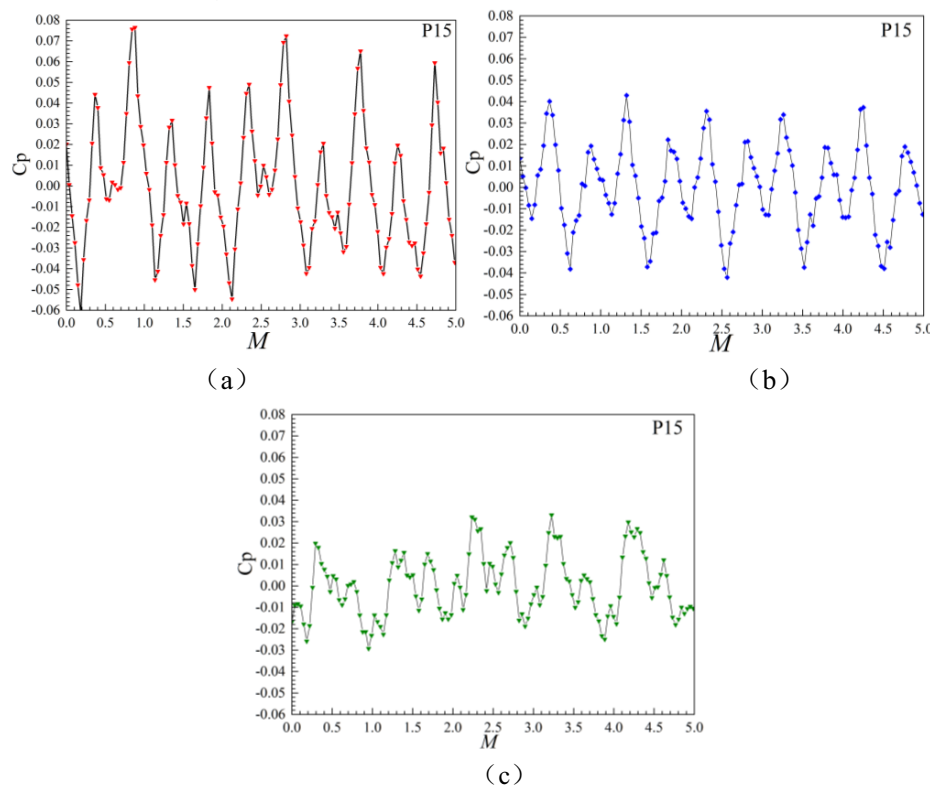


Figure 5. Time - domain diagram of monitoring points at the impeller outlet.

(a) $0.8Q_d$ (b) Q_d (c) $1.2Q_d$

At the guide vane outlet

The time domain characteristic curve of the pressure pulsation at the guide vane outlet of the axial flow pump under different flow rate conditions are shown in figure 6. The peak to peak values of the time domain curve of the pressure pulsation under the small flow rate conditions and the design flow rate conditions and the large flow rate conditions are 0.081, 0.060, 0.040 respectively. Due to the rectifying effect of the guide vane, the pressure fluctuation amplitude at the guide vane outlet is greatly decreased. Under the different flow rate conditions, the pressure pulsation at the guide vane outlet varies periodically with 2 peaks and 2 troughs in each impeller rotation period. Under the small flow rate conditions, the pressure pulsation of the guide vane outlet varies greatly, which is due to the small axial velocity and the large velocity circulation that causing the unsteady flow. With the increase of the flow rate, the axial velocity at the guide vane outlet is very large, causing the velocity circulation to be smaller and the flow fluctuation to be stable.

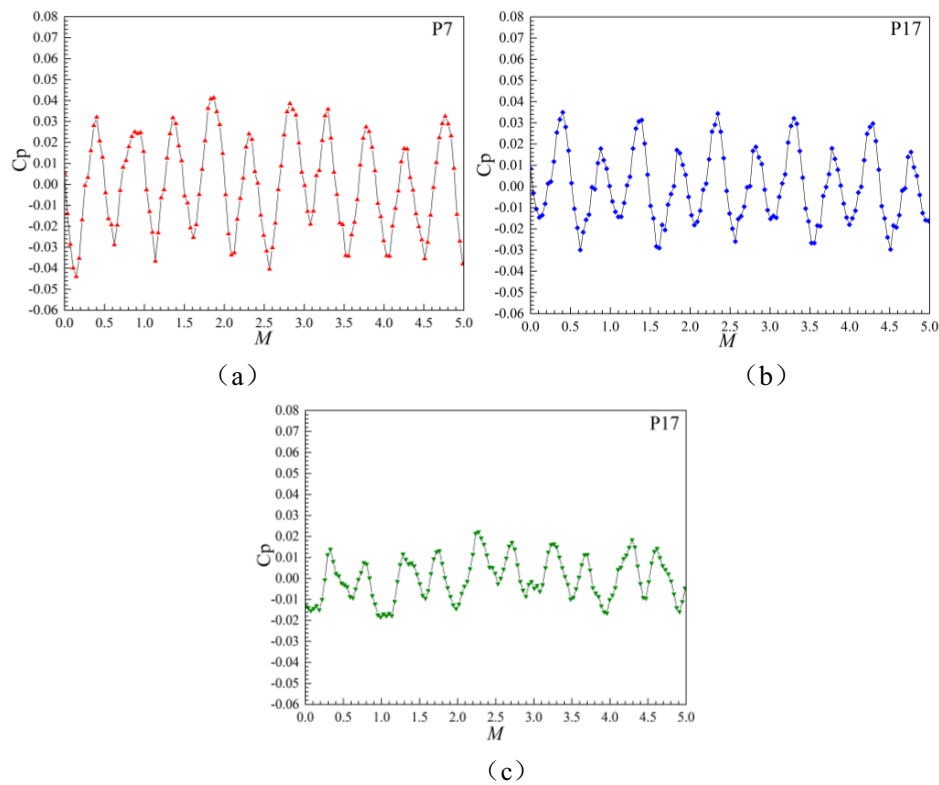


Figure 6. Time - domain diagram of monitoring points at the guide vane outlet.

(a) $0.8Q_d$ (b) Q_d (c) $1.2Q_d$

3.2 Analysis of the frequency domain of the pressure pulsation

The data of the pressure fluctuation experiment are processed by FFT, and the frequency domain characteristics of the pressure fluctuation under 3 typical different flow rate conditions are shown in figure 6-8.

Small flow rate conditions

The main frequency of the pressure fluctuation of the impeller inlet is 4 times of the frequency of pump impeller rotation under the small flow rate conditions, as shown in figure 7(a), this is because the flow of the impeller inlet is directly affected by the impeller rotation. The main frequency amplitude of the pressure pulsation at the impeller inlet varies evenly between different measuring points for the stability of the flow field of the impeller inlet, and the maximum pressure pulsation amplitude of the impeller inlet is 0.0172. The main frequency of the pressure fluctuation at the impeller outlet is twice of that of the pump impeller rotation, and the maximum pressure pulsation amplitude of the impeller outlet is 0.0172, as shown in figure 7(b). According to the references, the number of blades of the guide vane has no effect on the pressure fluctuation frequency between the impeller and the guide vane. However, the relative rotation between impeller and guide vane causes great interference between impeller and guide vane, which results in that the effect of the rotor-stator interaction on the pressure of the impeller outlet is greater than that of the impeller rotation. So the main frequency of the pressure pulsation deviates from the blade frequency. The main frequency of the pressure pulsation of the guide vane outlet is twice of the frequency of the impeller rotation, as shown in figure 7(c). The pressure pulsation excitation source at the guide vane outlet is the outlet velocity circulation. Under the small flow rate conditions, there is great velocity circulation at the guide vane outlet that leads to the difference of the pressure pulsation at the guide vane outlet. The complexity of the flow field of the guide vane

outlet leads to the low frequency pulsation at the guide vane outlet which affects the stability of the flow field.

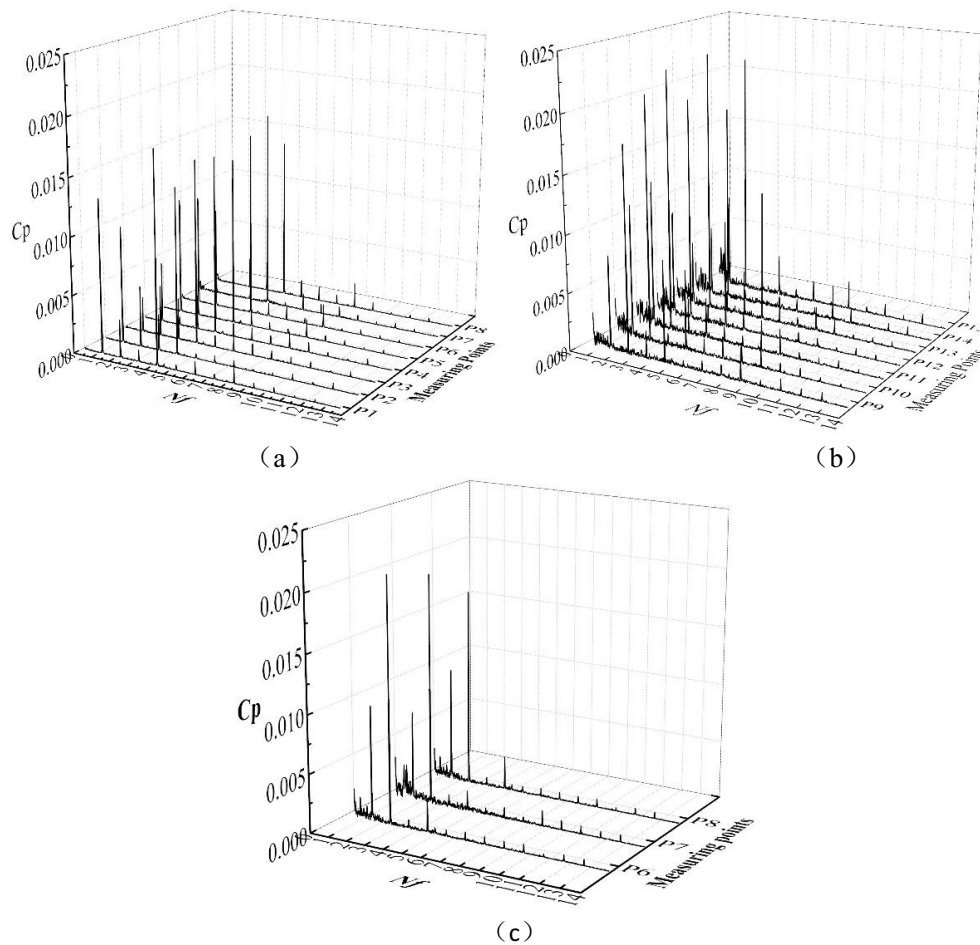


Figure 7. Frequency - domain diagram of monitoring points under small flow rate conditions.

(a) impeller inlet (b) impeller outlet (c) guide vane outlet

Design flow rate conditions

The main frequency of the pressure fluctuation of the impeller inlet is 4 times of the frequency of pump impeller rotation under the design flow rate conditions, as shown in figure 8(a), and the maximum pressure pulsation amplitude of the impeller inlet is 0.0151. The main frequency of the pressure fluctuation of the impeller outlet is twice of the frequency of pump impeller rotation under the design flow rate conditions, and the maximum pressure pulsation amplitude of the impeller outlet is 0.0175. The main frequency of the pressure fluctuation of the guide vane outlet is twice of the frequency of pump impeller rotation under the design flow rate conditions, and the maximum pressure pulsation amplitude of the guide vane outlet is 0.0161. The pressure pulsation of the impeller inlet under the design flow rate conditions is induced by the impeller rotation, which causing the main frequency of the pressure pulsation of the impeller inlet is the blade frequency of the impeller and the pressure pulsation of the impeller inlet varies uniformly. The amplitude of the pressure pulsation at different position of the impeller outlet fluctuate alternately; After the rectification of the guide vane, the amplitude of the pressure fluctuation of the guide vane outlet under the design flow rate conditions is significantly lower than that under the small flow rate conditions.

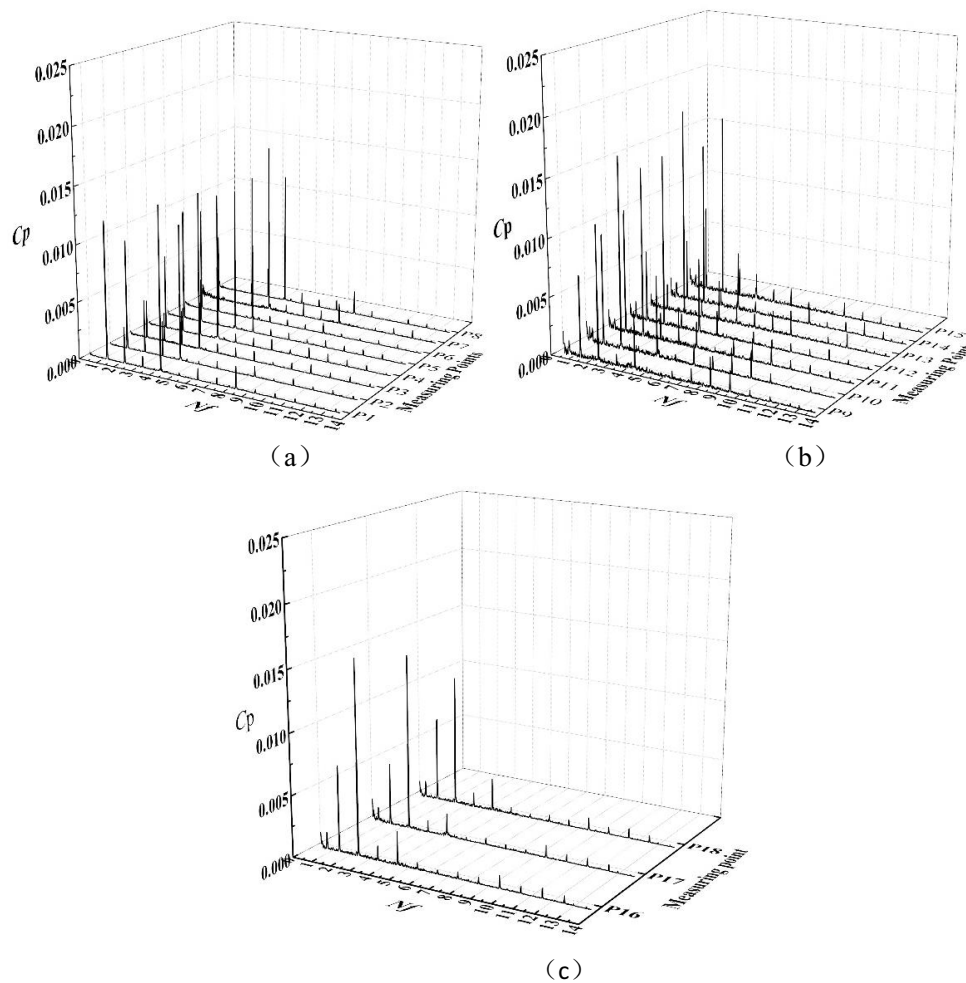


Figure 8. Frequency - domain diagram of monitoring points under the design flow rate. conditions

(a) impeller inlet (b) impeller outlet (c) guide vane outlet

(3) Large flow rate conditions

The main frequency of the pressure fluctuation of the impeller inlet is 4 times of the frequency of pump impeller rotation under the large flow rate conditions, as shown in figure 9(a), and the maximum pressure pulsation amplitude of the impeller inlet is 0.0149. The main frequency of the pressure fluctuation of the impeller outlet is twice of the frequency of pump impeller rotation under the large flow rate conditions, and the maximum pressure pulsation amplitude of the impeller outlet is 0.0112, as shown in figure 9(b). The main frequency of the pressure fluctuation of the guide vane outlet is twice of the frequency of pump impeller rotation under the large flow rate conditions, and the maximum pressure pulsation amplitude of the guide vane outlet is 0.0161, as shown in figure 9(c). There often easily occurs the inlet vortex below the flare tube under the large flow rate conditions. The pressure fluctuation of the impeller inlet under the large flow rate conditions is disorderly compared with that under the flow rate conditions without vortex. There is an obvious pressure gradient between the P5, P6 and P7 measuring points corresponding with the vortex area, which is because the inlet vortex enters the impeller and changes the pressure distribution of the impeller inlet. Along with the dissipation of the vortex energy, the pressure fluctuation will appear again at the location of the vortex. Until the vortex vanishes completely that the pressure distribution of the impeller inlet tends to be stable. Because of the complexity of the flow environment between the guide vane and impeller, the pressure pulsation at the impeller outlet is

disorder. As shown in figure 9 (a), the main frequency of the pressure fluctuation at the points P5, P6 and P7 are the blade frequency of the impeller.

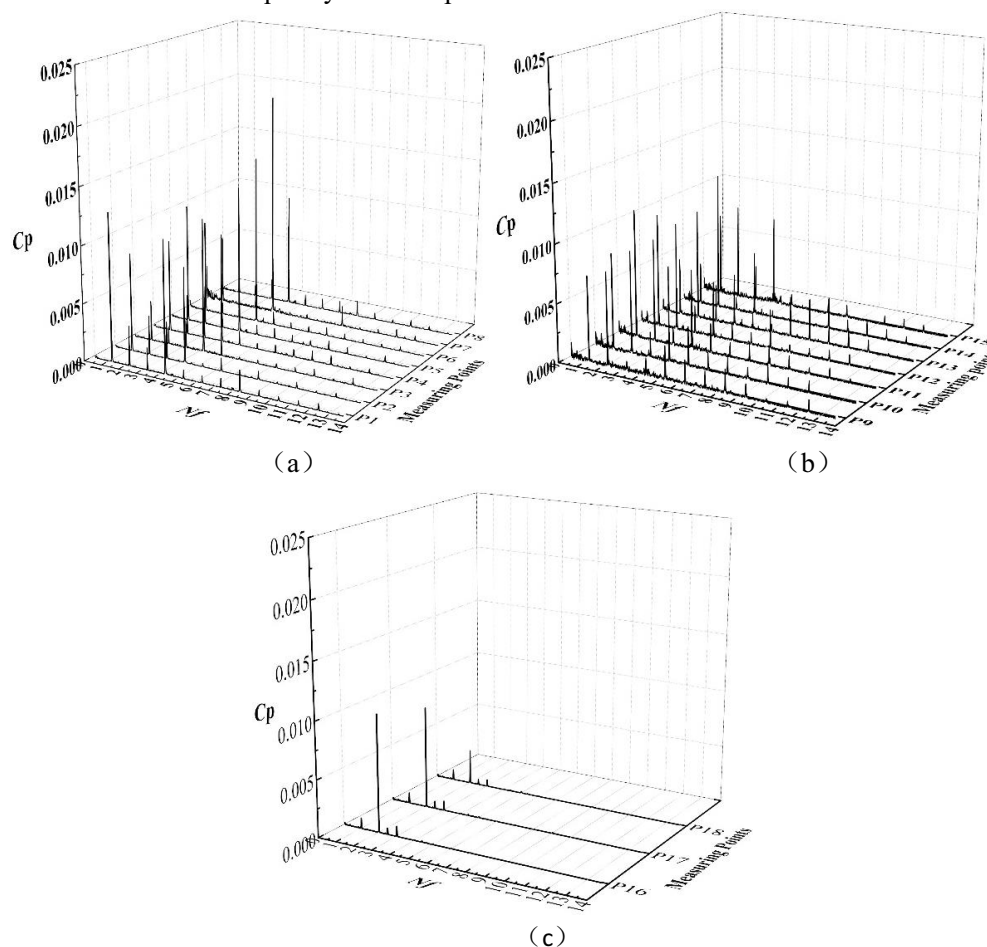


Figure 9. Frequency - domain diagram of monitoring points under large flow rate conditions.

(a) impeller inlet (b) impeller outlet (c) guide vane outlet

4 Conclusions

Based on the pressure pulsation characteristic test, with the pressure pulsation sensors installed at the impeller inlet, outlet and the guide vane outlet of the vertical axial flow pump unit, the pressure fluctuation of the impeller inlet, outlet and the guide vane outlet was measured under the vortex condition and the no-vortex condition.

The pressure fluctuation of the impeller inlet under the large flow rate conditions is disorderly compared with that under the flow rate conditions without vortex. The inlet vortex enters the impeller, and produces periodic pressure pulsation at the pressure field of the impeller inlet, which changes the pressure distribution of the impeller inlet, and affects the hydraulic stability of the flow field inside the impeller.

References

- [1] Chao L. Researches and developments of axial-flow pump system *J. Transactions of the Chinese Society for Agricultural Machinery*, 2015, **46**(6): 49-59.
- [2] Yun H. Main advances of research on vortex in pump sumps *J. Journal of Hydroelectric Engineering*, **23**(5):92-6.
- [3] WeiDong S, Hongfei L, Desheng Z, et al. Performance prediction and experiment for pressure fluctuation of interior flow in axial-flow pump *J. Transactions of the Chinese Society for Agricultural Machinery*, 2011, **42**(5):44-8.
- [4] Chao L, Li C, Jiren Z, et al. Numerical simulation of three-dimensional turbulent flow for opening pump sump *J. Transactions of the Chinese Society for Agricultural Machinery*, 2002, **33**(6):53-5.
- [5] GuoHui C, Fujun W. Applicability of turbulence models in numerical simulation of vortex

- flow in pump sump *J. Transactions of the CSAE*, 2008,**24**(6):31-5.
- [6] Fan Y, Chao L, Fangping T, et al. Analysis of hydraulic performance for vertical axial-flow pumping system with cube-type inlet passage *J. Transactions of the Chinese Society of Agricultural Engineering*, 2014, **30**(4): 62-69.
- [7] Fan Y, Yan J, Chao L, et al. Numerical analysis and performance experiment on diving tubular pumping system with symmetric aerofoil blade *J. Transactions of the CSAE*, 2012, **28**(16) : 60-67.
- [8] Shinji E, Hiroyuki T, Hidetoshi H, et al. Characteristics of flow field and pressure fluctuation in complex turbulent flow in the third elbow of a triple elbow piping with Small Curvature Radius in Three-dimensional Layout *J. International Journal of Hydrogen Energy*, 2010, **16**(21):70-7.
- [9] Arndt N, Acosta J, Brennen C, et al. Frequency Spectrum Analysis of High Frequency Cycle Square Wave Signal Based on Discrete Fourier Transform *J. ASME Journal of Turbomachinery*, 1999, **120**(3):157-78.
- [10] Arndt N, Acosta A J, Brennen C E, et al. Experimental investigation of rotor-stator interaction in a centrifugal pump with several vane diffusers. *J ASME Journal of Turbomachinery*, 1990, **112**(1):98—108.
- [11] Chao L, Haojie L, Yan J, et al. PIV Measurements of Intake Flow Field in Axial flow Pump. *J Transactions of the Chinese Society for Agricultural Machinery*, 2015, **46**(8):33-41.
- [12] Arndt N, Acosta J, Brennen C, et al. Rotor-stator interaction in a diffuser pump. *J ASME Journal of Turbomachinery*, 1989, **111**(3):213-21.