Experimental study on the influence of inlet distortion on the performance of single suction centrifugal pump

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Abstract; As a renewable energy source, water energy is indispensable in hydropower generation, and centrifugal pump is widely used in hydroelectric generation. But the centrifugal pump usually uses elbow pipe inflow due to the limitation of installation space, and the inflow distortion will lead to the decrease of pump performance and the increase of vibration. In this paper, the influence rule of inflow distortion on external characteristics and pressure pulsation of centrifugal pump was analyzed. The research results show that the inflow of elbow pipe will lead to the decrease of the head and efficiency of the centrifugal pump, which will decrease by 0.68m and 1.5% at the maximum under the design condition. The increase of bend angle will increase the pressure pulsation at the inlet of the centrifugal pump, which has an influence on the pressure pulsation around the volute at different positions, especially the pressure pulsation intensity at the tongue position significantly increases. The research in this paper can provide reference for the design and safe operation of inlet pipeline in practical engineering.

1. Introduction
Centrifugal pump has the advantages of high efficiency, simple structure, reliable operation, widely application of various fields of national economy, such as agricultural irrigation and water conservancy projects, urban water supply and drainage, oil and chemical industry, power plant[1]. In practical engineering, the centrifugal pump easy to cause the inlet flow distortion because of the installation space restrictions and import of sediment deposition, inconsistent with the uniform inflow in the process of design. The non-uniform inflow will have adverse effects on the external characteristics and pressure pulsation of centrifugal pump, resulting in increased pump vibration and even threatening the safe and stable operation of the entire pump system[2].

The inlet flow of elbow is one of the most common reasons for the inlet distortion of centrifugal pump[3], and the most direct phenomenon is the change of external characteristics. The inlet of the elbow pipe not only decreases the head and efficiency of the pump, but also increases the turbulent kinetic energy loss in the flow passage and increases the impact on the blade at the inlet[4]. It is found that the inlet flow distortion leads to the increase of radial and circumferential velocity of the impeller inlet, which results in the decrease of impeller performance and the decrease of head and efficiency[5].

The inflow distortion caused by the inlet mutation causes the fluid to backflow and deflow in the inlet pipe, and the fluid enters the pump in a relatively disordered form, leading to the decrease of the external characteristics of the pump[6]. However, further theoretical and experimental studies are needed to investigate the influence of different flow regimes on pump performance. Pressure pulsation
is one of the important reasons for vibration and noise of a unit \cite{7}, and is also an important index used to evaluate the stable operation of a unit. Different inflow conditions have a great impact on the pressure pulsation of equipment. Zhang et al. \cite{8} found that under non-uniform conditions, the impeller pressure pulsation increased with the increase of the inhomogeneity of incoming flow. However, there are few studies on the influence of elbow inlet on the performance of centrifugal pumps, and the influence mechanism of different elbow angles on external characteristics and internal flow is not clear. Therefore, the influence of different elbow angles on the performance of centrifugal pump was studied by combining experiment and numerical simulation.

2. Introduction of the model pump test platform

The single-stage centrifugal pump is selected as the research object in this paper. The main design and geometric parameters are shown in Table 1 and Figure 1. The main flow parts include inlet pipe, impeller, volute and outlet pipe. Among them, three inlet pipe models are designed with bending angles of 0°, 45° and 90°, as shown in Figure 2.

| Parameters                  | Symbol | Value |
|-----------------------------|--------|-------|
| Impeller inlet diameter/mm  | $D_1$  | 100   |
| Impeller outlet diameter/mm | $D_2$  | 192   |
| blade number                | $z$    | 6     |
| Design flow rate/(m³/h)     | $Q_d$  | 100   |
| Design head/m               | $H_d$  | 10    |
| Rotating speed/(r/min)      | $n$    | 1500  |

![Figure 1. Impeller hydraulic diagram](image)

![Figure 2. model of different inlet elbow](image)

The experiment in this paper was completed on a closed test bench of the State Key Laboratory of Ecological Water Resources in Northwest Arid Land, and the loop of the centrifugal pump test system is shown in Figure 3. It mainly includes centrifugal pump, water storage tank, electromagnetic flowmeter, import and export pressure gauge, valve, torque meter, motor and so on. During the test process, the centrifugal pump was adjusted to the rated speed by the frequency converter and kept unchanged, and the flow rate was adjusted by changing the opening of the outlet valve. In order to minimize the random error generated in the measurement process, the measurement data under the flow rate should be recorded after each adjustment until the flow rate is stable. The test data acquisition
system is mainly composed of pressure pulsation sensor, data acquisition program and computer part. Among them, the pressure pulsation sensor is the MPM480 high-frequency dynamic pressure transmitter provided by Mack Sensor Co., Ltd. The sensor selects the pressure sensor with high stability and reliability and the special circuit of the transmitter with high performance, which is used for the stable and reliable performance of the test measurement.

![Figure 3. Test system of centrifugal pump](image)

Figure 3. Test system of centrifugal pump

According to the existing conditions, a measuring point is arranged at the inlet and outlet of the centrifugal pump. Because of the asymmetrical structure of the centrifugal pump volute along the circumferential direction, four measuring points were arranged along the circumferential direction of the volute wall to analyze the change rule of pressure pulsation with water flow. The position of pressure pulsation sensor is shown in Figure 4. The measuring points of pressure pulsation at the volute are marked P1~P5 from the position of the tongue, and the measuring point P6 of the inlet pipe is located at the section 0.2m away from the pump inlet.

3. Result analysis

3.1. Influence of elbow Angle on external characteristics

Figure 5 shows the effect of bend Angle on head and efficiency of single suction pump. Under the design condition, the head and efficiency of the straight pipe are 9.53m and 88% respectively. After the inlet pipe is bent, the head and efficiency of the pump are reduced to some extent. The influence law of different elbow angles on the external characteristics of the centrifugal pump is consistent. The head and efficiency decrease with the increase of elbow Angle, but the range of decline is different. Under the design condition, when the bend Angle $\theta = 45^\circ$ and $\theta = 90^\circ$, the head decreases by 0.53m and 0.68m, respectively, and the efficiency decreases by 0.8% and 1.5%, respectively. The results show that the greater the elbow Angle is, the greater the decrease of centrifugal pump head and efficiency will be.

![Figure 5. Curves of external performance](image)
3.2. Pressure fluctuation experimental results and analysis

In this paper, the centrifugal pump speed $n=1500\text{r/min}$ and the number of blades is 6, so the shaft frequency $Fr = \frac{n}{60}=25\text{Hz}$ and the blade frequency $Fn = 6\times Fr = 150\text{Hz}$. In order to clarify the influence of non-uniform inflow on pressure pulsation of centrifugal pump, Fast Fourier Transform (FFT) was carried out on the collected data, and the frequency domain map of each measuring point was obtained. Referring to the dimensionless number of static pressure pressure coefficient $\eta^9$.

![Figure 6. Frequency domain diagram of pressure pulsation at inlet pipe](image)

Fig 6 is the frequency domain diagram of pressure pulsation at the inlet measuring point of centrifugal pump. On the whole, the pressure pulsation cycle law of the measuring points at different bend angles is similar, and the frequency mainly exists in the form of 5 times the frequency, and there are multiple frequencies at the same time. Different inlet conditions mainly affect the pressure pulsation amplitude. When the straight pipe enters the flow, the frequency amplitude is low and increases with the increase of the bend angle. When $\theta=45^\circ$ and $\theta=90^\circ$, the amplitude increases by 8.02% and 69.85% respectively. Through comparison, it can be seen that the amplitude of pressure pulsation at the impeller inlet frequency increases significantly with the increase of bend angle.

The asymmetry in the circumferential direction of the volute will cause the flow imbalance, and at the same time, the rotor/stator interference between the impeller and the volute will also produce large pressure pulsation. Therefore, the study of pressure pulsation inside the volute is the key to the study of pressure pulsation of centrifugal pump $^{10}$. Fig 7 shows the spectrum comparison diagram of pressure pulsation at the position of the tongue at different elbow angles $\theta$ of the inlet pipeline under design conditions and the blade frequency amplitude of each measuring point. Although the inflow modes are different, the main frequency in the pressure pulsation spectrum diagram of the tongue position under different inflow modes is blade frequency, and the amplitude of blade frequency is much greater than that at other frequencies. It shows that the change of inflow mode has little effect on the spectrum characteristics of pressure pulsation at the tongue position.

![Figure 7. Spectrum comparison diagram of pressure pulsation at different elbow angles](image)

Fig 7 shows the influence of different elbow angles on the amplitude of pressure pulsation blade frequency at each measuring point. At the measuring point P1, the blade frequency amplitude changed slightly when $\theta=45^\circ$, but increased by 20% when $\theta=90^\circ$. From the measurement points P2 to P4, the blade frequency amplitude decreases with the increase of the inlet pipe bend angle, and the maximum decrease of the blade frequency at P3 is 67.1%. At the P5 measuring point of the outlet pipe of the centrifugal pump, because its position is far from the impeller, the Angle of inlet pipe bending has little effect on the blade frequency amplitude at the outlet pipe.

In conclusion, the bend angle has different influence on the pressure pulsation at different circumferential positions of the volute. With the increase of bend angle, the pressure pulsation intensity at the position of the centrifugal pump tongue increases, while the amplitude of pressure pulsation at other measuring points improves slightly.
4. Conclusions

In this paper, based on the high-precision test platform and measuring elements, the performance of centrifugal pump under different elbow inlet conditions was systematically studied, and the following conclusions were drawn:

1. The inflow distortion has obvious influence on the external characteristics of the centrifugal pump. With the increase of bend Angle $\theta$, the hydraulic loss of each component increases and the external characteristics decrease. When $\theta=90^\circ$, the head and efficiency decrease by 0.68m and 1.5% in the design condition.

2. The pressure pulsation in the inlet pipe mainly exists in the form of 5 times rotational frequency, and the intensity of the pressure pulsation at the inlet of the centrifugal pump increases with the increase of the bend Angle.

3. The frequency of pressure pulsation at each measuring point along the circumferential direction of the volute is mainly the blade frequency and the amplitude decreases gradually. With the increase of pipe bending Angle $\theta$, the intensity of pressure pulsation at the position of the centrifugal pump tongue increases obviously, and the maximum increase is 20%.

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References

[1] CHALGHOUM I., ELAOU D S., AKROUT M., et al. Transient behavior of a centrifugal pump during starting period[J]. Applied Acoustics, 2016, 109: 82-89.

[2] Qian Fangqi, ZHANG Shujia, MAO Pengzhan. CFD Numerical Simulation of suction chamber of double suction Pump with high specific speed [J].Light Industrial Machinery, 2010, 28(06): 32-35.

[3] Yuan Shouqi, YUAN Jianping, Pei Ji et al. Internal flow and Operation energy saving of centrifugal pump [M].Beijing: Science Press, 2015.

[4] Yan Yu, LU Xiaofeng, ZHU Xiaolei. Influence of inlet elbow and prespoiler on centrifugal Pump Performance [J].Journal of agricultural engineering, 2013,29 (20): 74-81.

[5] Qiu Baoyun, Lin Haijiang, HUANG Jiyan, et al. Study on flow Field of Blade Inlet of Large Vertical Axial flow Pump and its Influence on water Pump [J].Journal of mechanical engineering, 2005,41 (4): 28-34.

[6] Hou Xiangtao, Wang Pengfei, Xu Zhongbin, et al. Influence of lower head of steam generator on inlet flow field of nuclear Main Pump[J].Journal of drainage and irrigation mechanical
engineering, 2016,34 (4): 277-282.

[7] Keller J, Parrondo J, Barrio R, et al. Effects of the pump-circuit acoustic coupling on the blade-passing frequency perturbations[J]. Applied acoustics, 2014, 76: 150-156.

[8] Zhang Liping. Numerical Simulation of pressure Pulsation in axial flow Pump under Non-uniform Inflow condition [D]. Yangzhou: Yangzhou University, 2013: 38-52.

[9] Zhang Hao, JING Ye, XIA Guosheng, et al. Influence of blade inlet impact Angle on centrifugal pump operation[J]. Internal Combustion Engines and Accessories, 2019(09): 79-81.

[10] Xianwu Luo, Weixiang Ye, Numerical investigations of the energy performance and pressure fluctuations for a waterjet pump in a non-uniform inflow [J], Renewable Energy 153 (2020) 1042-1052.