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Experimental study on two-way flow passages in pumping system †

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Abstract

Based on the model test of pumping system with two-way flow passages, the flow characteristic and flow pattern in two-way outflow passage are specially observed and analyzed. The various schemes are compared by means of test and the measures for improving flow pattern in outflow passage are come up with by the authors. This research possesses reference value for pump selection and flow passages design of analogous pumping station.

Keywords: Two-way flow passages; Pumping system; Model test

1. Introduction

Pumping stations with two-way inflow passages and two-way outflow passages possess functions of pumping irrigation, pumping drainage, irrigation by gravity and drainage by gravity. So they have advantages of low construction cost, easy management and better total benefits.

In large-sized vertical shaft pumping stations with two-way flow passages, there are various intake flow passages such as elbow-like put together back to back, bellmouth-like and culvert-like one and also there are different types of outflow passages such as having-pressure pipe, pressure culvert and open flume (Liu, 2001; Wang, 2004; Zhang, 1994)[1-3].

Nowadays, some existing pumping stations with two-way flow passages possess ether improper design in shaped lines and structural dimensions or improper arrangement of flow parts such as exposed rotational shaft in outflow passage resulting in lower system efficiency, vibration and cavitation. Even more some pumping stations need technical reformation when they are built newly (Chen, 2001)[4]. To be able to design reasonably and to ensure to operate efficiently without accident, it is full necessary to study on pumping system and to observe and analyze carefully on flow characteristic and flow pattern in the flow passages by model test and to put forward valid measures of improving flow pattern.

2. Experimental system and test methods

2.1 Experimental system

The type of the prototype pump is 1400ZLB-125, which is a vertical shaft axial-flow pump. The diameter of the impeller is $D_P = 1200$ mm; the revolution is $n_P = 375$ r/min. Under the design condition, the head of the pump is 4.53 m and the flow rate is 5.6 m^3/s. The model pump can be selected according to the principle of having equal specific speed approximately between prototype and model type pump. The type of the model pump is 350ZLB-100. The diameter of the impeller is $D_M = 300$ mm; the revolution is $n_M = 1450$ r/min; the blade angle is 1 degree. The inlet and outlet flow passages of the prototype pump are constructed by concrete. The roughness of the flow parts is 0.014. The material of which the inner wall of the flow passages of model pumping system is made up should be determined as glass or organic

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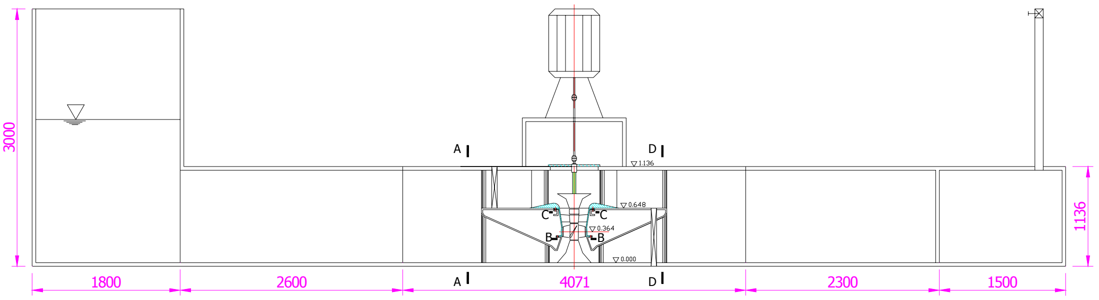


Fig. 1. Profile of arrangement of model pumping system.

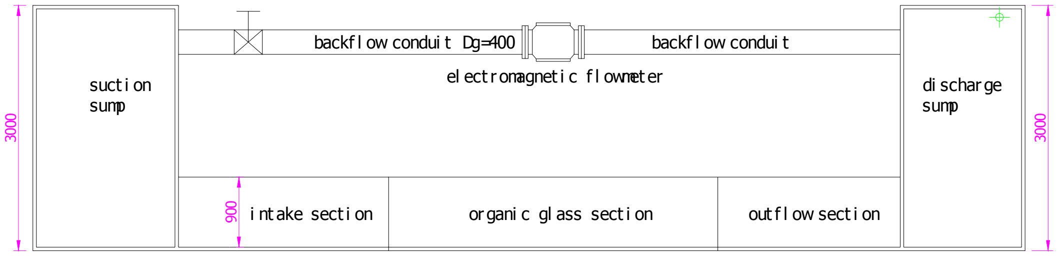


Fig. 2. Plane of arrangement of model pumping system.

glass in light of the principle of similar conversion. The considerations of the demands of construction and safely operation and the convenient observation of flow pattern are taken account, so two sidewalls of inlet and outlet flow passages are constructed by organic glass so as to observe flow pattern easily, and the other inner surfaces of flow passages are coated with antirust paint and paraffin to meet the demands of similarity of roughness between model and archetype. The experimental system is shown in Fig. 1 and Fig. 2.

The flow rate, the shaft power and the rotational speed are measured by electromagnetic flow meter, power gauge and photoelectric tachometer respectively. The head of the pump can be worked out on the basis of pressure differences and the flow velocity.

2.2 Test methods

2.2.1 Measurement of the flow rate

The flow rate is measured by electromagnetic flow meter of which precision is 0.3 level. Along the direction of flow, the length of straight pipe of back flow before the flow meter must be 10 times larger than the diameter of the back flow pipe, and the length of straight pipe after the flow meter must be 5 times larger than the diameter of the back flow pipe. The data in a period of time are collected by secondary instruments, and then its average value is used as the discharge of the pump under the operation condition. The limit error δ_Q of measurement of the flow rate is ±1.18%.

2.2.2 Measurement of pressure and head

The pressures are collected by pressure sensors of which precision is 0.3 level on the inlet cross section A—A (as shown in Fig. 1) of intake flow passage and on the outlet cross section of outflow passage. The data of pressures on the inlet cross section B—B (symmetric four points should be measured) of the pump and on the outlet cross section of the pump C—C (symmetric two points should be measured due to technique) are collected by respective sensors, and then the averages are taken. The total energy of each section can be figured out by its average pressure plus velocity head corresponding to the flow rate under the operation condition, thus the head of the pump, the head of system, the hydraulic loss of each segment of flow passage and its resistant coefficient can be gained. The limit error δ_H of measurement of the head is ±1.60%.

2.2.3 Measurement of power

The input power of electric motor is measured by power gauge of which precision is 0.3 level, and its output power (namely shaft power of the pump) can be obtained by conversion of the characteristic curve provided by manufacturer. The limit error δ_N of measurement of the head is ±1.33%.

2.2.4 Measurement of revolution and noise

The rotational speed of the pump is measured by photoelectric tachometer of which precision is 0.05 level. The limit error δ_n of measurement of the revolution is ±0.21%. The noise of the pump is measured by sound level meter.

2.2.5 Observation of flow pattern in intake and discharge passages

To observe the flow pattern in intake and outflow passages corresponding to various schemes under different operation conditions, the flow indicator bars with red silk threads are respectively arranged in the initial cross-section along the direction perpendicular to the streamline. The flow indicator bars which cross the separation pier of flow passage consist of high and low bars in twain. There are flour red silk threads on each of them. The flow pattern in flow passages can be observed clear with the aid of red silk threads.

3. Test results and analyses

3.1 Flow condition in intake passage and analyses

The butt-jointed bell type of intake flow passage is adopted by authors in this model test. The bell type intake passage is designed according to 'the code of design of pumping station'. The flow pattern under all operation conditions is observed with the aid of red silk threads. The relative interval distances between all red silk threads with 0.4 m long are comparatively stable. There is a little fluctuation in the end of the threads and the latitude of fluctuation is less than 1 cm. It is obvious that the flow pattern in intake flow passage is stable. It is confirmed that the design of intake flow passage is met the requirements of engineering.

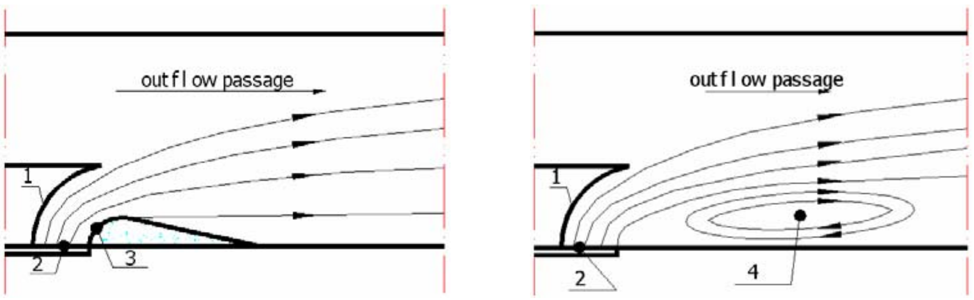
3.2 Flow condition in outflow passage and analyses

3.2.1 The effect of the outlet of pump and separation pier on the flow pattern in outflow passage

The model pump without the outlet bend is transformed from ordinary axial-flow pump. The performance of the ordinary pump with discharge bend is changed. The path of flow through pump is shortened because of without the outlet bend. A majority of kinetic energy can not be converted to pressure head in time. The water arrives at the outlet of pump quickly and diverges abruptly, which results in greater energy loss. Furthermore, the water with greater energy flows into discharge passage quickly and the loss in pump will augment due to sudden change of velocity gradient. So the connection of the outlet of pump with discharge passage is very important. The hydraulic loss coefficient caused by optimal connection determined finally by the authors is 1 time less than bad connection. Thirdly, bad connection of the outlet of the pump with the discharge passage may result in uneven pressures in the region of the connection. Back flows or vortexes, which are one of causes of the occurrence of vibration and noise during operation, will appear near the connection.

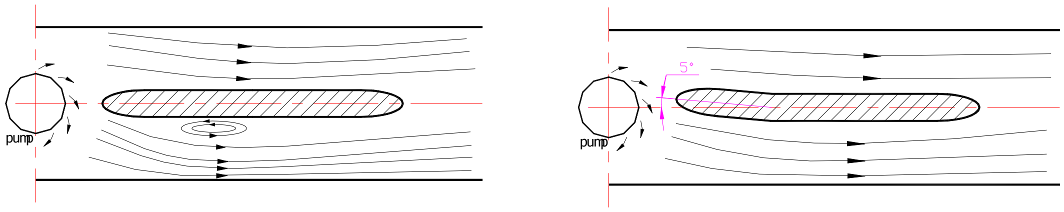
Uneven pressures occur in both sides of discharge passage cross section because of the effect of the rotational direction of pump, which is also one of main factors causing vibration of pump. So the measure by mounting separation piers in discharge passage is taken so as to lessen the difference of energies between both sides of discharge passage cross section caused by the effect of the rotational direction of pump. The separation pier also divides discharge passage into right-and-left two bores to stabilize hydraulic structures. It is observed that uneven pressures occur in both sides of separation pier. The upper row and lower row streamlines tend to keep away from separation pier sidewall in the bore where the separation pier sidewall points towards the direction of the rotation of the pump; the upper streamlines tend to approach separation pier sidewall and the lower streamlines tend to keep away from separation pier sidewall in the other bore when inverse bell-mouthed outlet is not mounted. There are two causes. One is bad connection of the outlet of pump with discharge passage resulting in excessive flow velocity of upper water and back flows of lower water in the region of circumfluence; the other is uneven pressures occurrence in both sides of separation pier with the effect of the rotational direction of pump, and the pressure withstood by separation pier sidewall where the separation pier sidewall points towards the direction of the rotation of the pump is more than that on the other sidewall.

Aiming at above-mentioned questions and phenomena, we took two measures improved in this experiment. One is that the inverse bell-mouthed outlet is put up as shown in Fig. 3. The function of the bell-



(a) With inverse bell-mouthed outlet (b) Without bell-mouthed outlet

Fig. 3. Comparison inverse bell-mouthed outlet with abrupt divergent outlet (1 flow-guided cap, 2 exit of pump, 3 inverse bell-mouthed outlet, 4 back flow region).



(a) Plane of discharge passage with conventional baffle block (b) Plane of discharge passage with deflection baffle block

Fig. 4. Comparison conventional baffle block with deflection baffle block.

mouthed inlet of the pump is to lead smoothly water from intake passage to the inlet of the pump and the inverse bell-mouthed outlet can also lead smoothly water from the outlet of the pump to discharge passage in the same way. The other is to transform conventional baffle block into deflection baffle block which possesses dual functions of guiding flow and separating flow as shown in Fig. 4, which is able to lessen or eliminate disequilibrium of pressures and flow rates in both sides of baffle block. The concrete measure is to deflect head section about 0.1 m long 5 degree from ordinary position towards the rotational direction of the pump by comparing again and again. The back flow near the exit of the pump gets hold of improvement immediately by means of putting up the inverse bell-mouthed outlet and deflection baffle block.

3.2.2 The effect of flow-guided cap on the flow pattern in outflow passage

To improve the flow pattern near the exit of pump and within the discharge passage, flow-guided cap is mounted behind the exit of the pump (i.e. behind guide vane body). It is fastened on the shaft sleeve of the pump shaft. The height ΔH, as shown in Fig. 5, of the flow-guided cap away from the exit of the pump has very important effect on the flow pattern within the discharge passage, so the determination of the height is extremely important. To find out the optimal height ΔH, the contrastive experiments including seven values of different height ΔH are conducted. There are two methods to distinguish whether better height or worse height. One is to observe depth of parallelism between red silk threads. The other is to analyze the changes of hydraulic loss coefficients S within discharge passage. The height of the flow-guided cap is changed step by step during experiments and it gain 2 cm each time so as to find out the height ΔH corresponding to minimum value of hydraulic loss coefficients S within discharge passage.

The contrastive experiment shows that too big or too small the height of flow-guided cap will deteriorates flow condition and enhances the hydraulic loss within the discharge passage. The relative of the height ΔH of flow-guided cap versus hydraulic loss coefficients S within discharge passage is shown in Fig. 6.

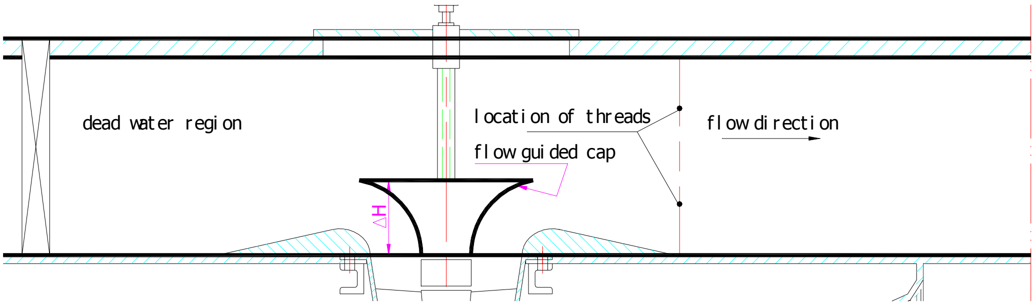


Fig. 5. Profile of outflow passage and layout of red silk threads.

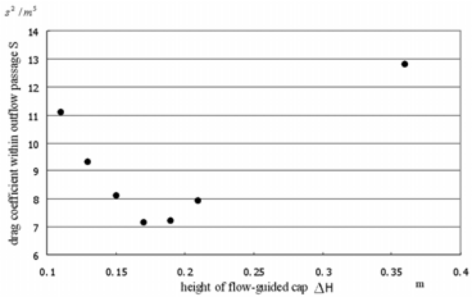


Fig. 6. Relationship of the height ΔH of flow-guided cap and hydraulic loss coefficients S .

4. Conclusions

The varieties of schemes in the test show that the height of the flow-guided cap has very important influence on the flow pattern and on the hydraulic loss in outflow passage. When the height is too big, the water current out of the exit of the pump will rush at the top of the cover and then retrace. The vortex will occur easily at the lower region in outflow passage. The hydraulic losses will increase. When the height is too small, the flow velocity at the exit of the pump will enhance, and the hydraulic losses within the discharge passage will also increase. The optimal height, which is 17 cm, of the flow-guided cap is figured out by comparing and analyzing during test.

Test shows that if the water out of the exit of the pump is led to discharge passage directly after the outflow bend is taken out the flow pattern within the discharge passage will be deteriorated and the hydraulic losses will increase remarkably. The scheme of putting up inverse bell-mouthed outlet is put forward. The water out of the exit of the pump is led to the discharge passage smoothly. The back flow in lower story within the discharge passage is eliminated and the hydraulic losses within the discharge passage are also decreased. So the inverse bell-mouthed outlet is necessary in this system.

From the top view of the outflow passage, the flow water out of the pump tend to rushing at the sidewall of the baffle block and the back flow will occur at the back of the baffle as a result of the increase of the hydraulic losses within the discharge passage since circumfluence out of the exit of the pump is not eliminated completely. The deflection baffle block, which the head section deflect 5 degree from ordinary position towards the rotational direction of the pump, instead of conventional baffle block will obviously improve the flow pattern within the discharge passage.

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