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Study of hydraulic performance and pressure pulsation characteristics of the grinder pump in case of clogging

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In order to study the variation rule of head, efficiency and the shaft power of the non-blocking submersible grinder pump, as well as the influence of the static cutter runner clogging on its pressure pulsation when the static cutter runner is clogged, this study adopts, on the basis of experiments, RNG k-Epsilon turbulence model to carry out steady and unsteady calculation about the computational domain of the grinder pump. By analyzing 28 different clogging cases of the static cutter runner, it is found that with the clogging degree of the static cutter runner increasing, the head changes in shape of a parabola, the maximum efficiency point of the grinder pump deflects to low flow point, and the high efficiency area of the pump narrows. In the low flow area, the throttling action between the dynamic cutter and static cutter is the most important factor that affects the pump characteristics variation rule, whereas, in the high flow area, the throttling action between the dynamic cutter and static cutter, the clearance cavitation at the radial clearance, and the vortex-type cavitation on the edge of the impeller outlet together affect the pump characteristics variation rule of the submersible grinder pump; inside of the submersible grinder pump, when the static cutter runner is clog-free or part of the runner is not completely clogged, the passing frequency of the dynamic cutter is the most important factor that affects the pressure pulsation, whereas, when part of the static cutter runner is completely clogged, the dynamic-static interaction effect between the dynamic cutter and static cutter is the most important factor that affects the pressure pulsation.

Key words: Submersible Grinder Pump, turbulence model, Channel blockage, pressure pulsation, cavitation.

INTRODUCTION

With the rapid development of industry and agriculture, more and more sewage thus generated contains fiber and other impurities, ordinary sewage pump is prone to be clogged during the run time so that it is unable to meet the requirement of discharging substance with high fiber impurities, as a result, sewage pump with auxiliary cutting or grinding device is more and more widely used. Therefore, the submersible grinder pump is widely used in industries such as municipal, sewage treatment, environmental protection, light industry, mining, study making, water conservancy and chemical industry, etc.

Scholars both at home and abroad have made a deep study into the submersible pump, among which for the first time in 1979, Kratzer A [1] systematically summarized design and model selection issues of the sewage pump, and emphatically analyzed the lossless performance of various pump when discharging materials; J.A. Escobar [2] studied safety of the submersible pump by analyzing submersible pump system breakdown caused by stress corroded fitting bolt through X-ray fluorescence spectrum; Parviz Ali-Zadea [3] carried out study on submersible pump noise, analyzed the relations between interference level and noise level and provided a noise elimination plan; Hernandez - Solis, A and Carlsson, F [4] studied the relation between submersible centrifugal pump cavitation and motor power capacity, diagnosing cavitation and impeller damage of the submersible centrifugal pump by monitoring motor power capacity and current flow; Liu, Yingyuan [5] mainly studied the cavitation flow characteristics of the rotor pump and discussed several factors affecting the cavitation, including rotation speed, pressure difference and gap size and inlet pressure; Lee, Kyoung - Hoon [6] carried out experiments on the effects of cavitation flow instability of the double-blade axial inducer and observed the internal asymmetric cavitation and cavitation phenomenon of the inducer; Cudina [7] established correlation with pump cavitation through noise spectrum generated by cavitation, so as to test the cavitation; Domestic scholars Wang Songlin [8] and Wang Yushi [9], etc. verified the feasibility of the RNG k-ε model and the transport equation cavitation model through experiment, finding that pressure pulsation intensity under cavitation condition was 2 times as much as that under non-cavitation condition, and pressure pulsation under low flow condition was about 5 times as much as that under design condition; Zhu

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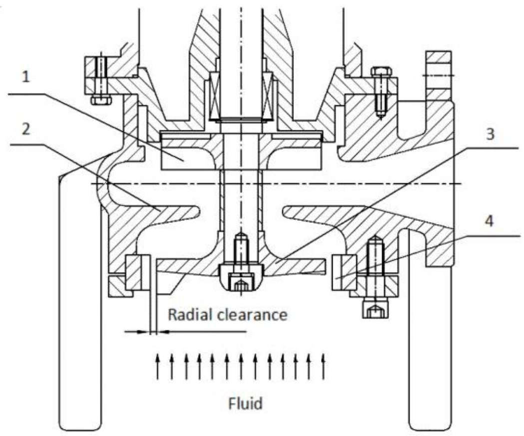
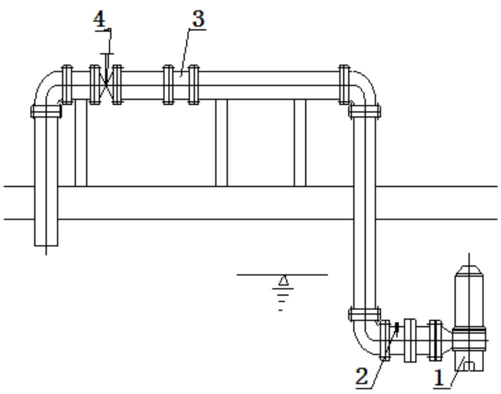
Rongsheng and Wang Zhenwei [10, 11], etc. studied the effects on the external characteristics of the non-blocking submersible grinder pump with or without grinding device and the clearance between dynamic cutter and static cutter. It can be found that few scholars both at home and abroad studied the submersible pump performance of all aspects under clogging condition.

This study carries out simulation studies on submersible grinder pump static cutter on the basis of experiment, mainly studies the head, power capacity and efficiency variation rule and internal flowing characteristics of the static cutter runner under different clogging conditions, and analyses frequency domain and time domain characteristics of the internal pressure pulsation of the pump when static cutter runner is clogged, so as to learn the internal flow characteristics of the non-blocking submersible grinder pump and to provide theory basis for the optimization design of grinder pump.



1.Pump casing 2. Impeller
3. Dynamic cutter 4.Static cutter

(a)



1. The Test pump 2. Piezometer tube
3.Regulating valve 4. Flowmeter

(b)

Fig. 1. Structure sketch and diagram of the test device.

NUMERICAL SIMULATION AND EXPERIMENTAL PART

Experiment table and Experiment method

Use GSP-22 non-clogging submersible grinder pump as the experimental pump, with clean water as the transmission medium. The pump performance test is carried out at the open test bed in Jiangsu University's National Water Pump and System Engineering Technology Research Center. The entire test system consists of GSP-22 non-clogging submersible grinder pump, outlet piping, comprehensive experiment table, TPA-3 pump product parameter measuring instrument, FLK1151 pressure transmitter, and NSKYLWGY liquid turbine flowmeter, etc. In order to verify the pressure pulsation characteristics of the CFD simulation, use CY301 high-precision high-speed intelligent pressure sensor to collect the pressure pulsation data at both static cutter and volute outlet. As the submersible grinder pump works underwater during the experiment, use D28 hose to provide waterproof protection to CY301, the structure sketch of pump and test device diagram, static cutter models with different partial clogging degrees and the experiment site as shown in figure 1(a),1(b), 2,3

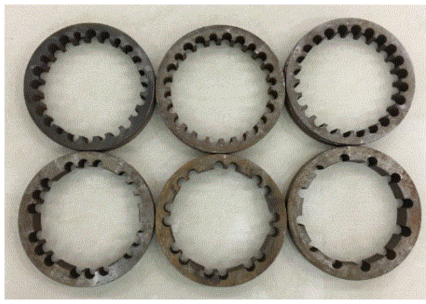


Fig. 2. Static cutter models with different partial clogging degrees

Fig. 3. Experiment site

This experiment is divided into two parts, including pump external characteristic experiment and pump pressure pulsation characteristic experiment. The pump external characteristic experiment includes 8 kinds of static cutter runner clogging schemes with 13 flow point tests for each scheme. The experiment is started by the shutoff valve. Changing the real-time flow capacity (0 ~ 35 m3/h), the pump test system can record inlet and outlet pressure and shaft power of the centrifugal pump, and automatically calculate the head, shaft power and efficiency of the pump. Pump pressure pulsation experiment and pump external characteristic experiment are carried out simultaneously. Set the collecting zero point in the data-collecting software NetSensor before start the pump, set the sampling frequency as 2000 Hz, sampling time 30s, then collect data respectively at flow capacity points of 0.5Q, 0.7Q, 1.0Q, 1.2Q and 1.5Q.

Numerical methods

This study uses the software Pro/E to make model and adding a segment of water body in front of cutter inlet and at volute outlet, so as to guarantee higher stability of the simulation results. The entire model included water inlet, dynamic cutter water body, static cutter and rear runner water body, impeller water body, volute water body and water outlet, as shown in figure 4.

This study uses the ANSYS-CFX 14.5 to conduct numerical simulation, including steady calculation and unsteady calculation. As the static cutter of non-blocking submersible grinder pump is composed of multiple narrow half-round runner, and structured grid can take better control over the grid number than unstructured grids, and easy to converge. Therefore, use meshing software ICEM to make structured mesh division to all water body parts, and make unstructured mesh division to static cutter and rear runner water body. The grid qualities of minimum angle of each water body part are shown in Table 1.

As the grid quality directly affects the result of numerical simulation, it is only when the increase of grid number has little influence on the results that the accuracy of simulation calculation can be determined. In order to determine whether the grid number and quality of the computational domain meet the practical requirements, independence inspection on the grid of the model is carried out based on Standard k-ε and RNG k-ε turbulence models respectively. Dividing the model on the basis of different mesh density, the calculation shows that when the grid number reaches 12037.56 million, the design-point head variation range of grinder pump is below 5%, and when the grid number reaches up to 15832.73 million, the design-point head variation range of grinder pump is below 1%, indicating that the calculation results has nothing to do with the grid number. Considering the accuracy and efficiency of calculation, numbers are finally determined as follows: inlet water body grid number 334656, dynamic cutter water body grid number 1619.04 million, static cutter and rear runner water body grid number 4832.16 million, impeller water body grid number 4092 million, volute water body grid number 2100.5 million, outlet water body grid number 623.1 million, and the total model grid number 16613.36 million.

As the CFX has introduced a large number of turbulence models, it can run simulation of most of the hydraulic rotating machinery. In order to make the simulation result closer to reality, this study chooses the RANS two-equation model of Standard k-Epsilon model and RNG k-Epsilon model, the Shear Stress Transport model, the BSL model and k-Omega model. Big difference exists among the velocity distribution at different locations of the whole water domain. Calculation shows that the minimum Reynolds number at the pump inlet is and the maximum Reynolds number at the static cutter runner is , in which the Reynolds number range applies to the 5 kinds of turbulence model above.

Comparing the above 5 kinds of turbulence model simulation results (head variation curve and efficiency variation curve) and experimental data, it is found that in the low flow area (0 ~ 0.6 Q), the k-w model coincides best with the experimental data, followed by BSL > RNG k-ε > SST > Standard k-ε; around the design point (0.7 ~ 1.2 Q), the RNG k-ε model coincides best with the experimental data, followed by SST >k-w > BSL >k-ε; in the high flow area (1.2 ~ 2.0 Q), BSL model coincides best with the experimental data, followed by RNG k-ε>k-w > Standard k-ε> SST, as shown in figure 5.

Table 1. Grid quality of each part.

Grid	Water inlet	Dynamic cutter water body	Static cutter water body	Impeller	Volute	Water outlet
Quality	0.70	0.43	0.41	0.57	0.45	0.72
Min angle	48	29	23	38	33	53

CONCLUSIONS

(1) By the 28 established static cutter water body models with different clogging degrees, it is found that as the static cutter runner clogging degree increases, the head declines in shape of a parabola, the maximum efficiency point of the grinder pump shifts to low flow capacity point, and the high efficiency area of the pump narrows. The throttling action between dynamic cutter and static cutter at low flow area is the most important factor affecting the pump characteristics variation rule, whereas, the throttling action between dynamic cutter and static cutter, clearance cavitation at the radial clearance as well as the vortex-type cavitation at the impeller outlet at high flow area together affect the pump characteristics variation rule of the submersible grinder pump.

(2) Through analysis of the time domain and frequency domain of inlet and outlet pressure pulsation of the submersible grinder pump in different clogging schemes, it can be found that in the submersible grinder pump, when the static cutter runner is clog-free or partly not completely clogged, the passing frequency of the dynamic cutter is the most important factor affecting the pressure pulsation; when part of the static cutter runner is completely cogged, the dynamic-static interaction effect of the dynamic and static cutter is the most important factor affecting the pressure pulsation.

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