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Visualizing test on the pass-through and collision characteristics of coarse particles in a double blade pump

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Abstract

As the key equipment in deep ocean mining, the slurry pump suffers from wear and blocking problems. In this paper, high-speed photography technique is applied to track the movement rule of single particle of the coarse particle solid−liquid two-phase flow in a double blade slurry pump. The influences of particle diameter and particle density on the pass-through and collision characteristics of particles are analyzed as well. The results show that the average of the passing pump time first decreases and then increases when the particle diameter increases. The average of the passing pump time decreases by 22.7%, when the particle density increases from 1.09 g/cm^3 to 1.75 g/cm^3. Besides, the particle density has great influence on the location where the particle hits the tongue. Most particles of 1.09 g/cm^3 hit the tongue on the left side, while collision location of particles of 1.75 g/cm^3 is mainly on the top and at the right side of the tongue. The research can provide a basis for the optimization design of slurry pump in deep ocean mining system.

Keywords: Coarse particles; High-speed photography; Double blade pump; Pass-through characteristics; Particle collision

1. Introduction

With the rapid development of world industry, the mineral resources on land are depleting. But the deep sea, as the last undeveloped area on the earth, is very rich in mineral resources. Recently, the research of deep-sea polymetallic mining technology has been extensively studied, and it is generally believed that the slurry pump hydraulic pipe lifting system has the most industrial application prospects for its high efficiency. However, slurry pump as the key equipment for this system has the clogging and wear problem, which seriously damages its life (Zou, 2007; Xiao, 2000; Walker and Robbie, 2013). The traditional tiny particle solid−liquid two-phase flow research can't meet the design requirements of the coarse particle pumping system for deep-sea mining, where the particle size is larger than 2 mm. This is because the physical properties between coarse particle and fluid phase are quite different in the coarse particle pumping system. Coarse particles are extremely easy to clog the flow passage, which may result in great decrease of the efficiency, reliability and service life of the pump, and serious blockage of flow passage would even threaten the safety of the system and personnel (Duan et al., 2012; Adewumi et al., 2003; Ma et al., 2007).

Therefore, the study of the coarse particle solid−liquid two-phase flow has become a hot research topic in recent years. Xia et al. (2004) study on the variation of the pressure gradient in the vertical pipe flow of the coarse particles of manganese nodules, and the calculation method of the pressure gradient in the process of long distance lifting of the coarse particles is proposed based on this experiment. The effects of particle size, particle density, particle volume fraction and Reynolds number on the shear force between particle and wall were studied by Bartosik (2010), the results show that

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the influence of the particle diameter is the most significant. Wijk et al. (2012) compared the resistance and slip velocity in vertical lifting flow under different shapes of coarse particles, and pointed out that the interference settling theory (Gidaspow, 1994) goes well with the slip velocity law of coarse particles in vertical lifting flow. Han and Liu (2002) experimentally investigated the hydraulic lifting resistance loss of coarse particles in the vertical pipe and obtained the influence of solid–liquid two-phase flow concentration, particle volume fraction and shear modulus on the resistance loss.

At present, although many researches on the coarse particle solid–liquid two-phase flow focused on the block, pressure gradient change and resistance loss, less attention is paid to the motion law of coarse particles. Besides, studies of coarse particle solid–liquid two-phase flow are mainly in pipeline, rarely in a pump. In order to develop theories on solid–liquid two-phase flow, it is urgent to carry out the research on the coarse particles solid–liquid two-phase flow mechanism in the pumps.

The main motive of this paper is to research the single particle motion trajectory of coarse particles solid–liquid two-phase flow in a double blade slurry pump by using high speed camera system. Also, the effects of particle size and particle density on pass-through and collision characteristics are analyzed, which can help to design a slurry pump.

2. Model pump and test rig

2.1. Model pump

A double blade centrifugal pump is chosen as the research model, the designed flow rate is 25.86 m^3/h, the designed head is 2.68 m, designed rotation speed is 750 rpm, and the specific speed is 111($n_s = 3.65nQ^{0.5}H^{-0.75}$, r/min, m^3/s, m). The pump consists of 3 parts, including the semi-spiral suction chamber, the impeller and the volute. The structure of the pump is shown in Fig. 1. For the convenience of high speed camera test, pump shaft and the pump inlet are at the same side and both the impeller and the volute are made of organic glass. The structure parameters of the double blade centrifugal pump are shown in Table 1.

Table 1
Main parameters of the research model.

Parameter	Sign	Value
Impeller inlet diameter	D_j (mm)	90
Impeller outlet diameter	D_2 (mm)	201.2
Impeller outlet width	b_2 (mm)	44.6
Blade number of impeller	Z_B	2
Blade wrap angle	φ_1 (°)	177.5
Blade outlet angle	β_2 (°)	41
Volute inlet diameter	D_3 (mm)	212
Volute inlet width	b_3 (mm)	47

2.2. Test rig

A double blade pump visualization testing system was built in Jiangsu University. The sketch of the test rig is shown in Fig. 2 and its picture is shown in Fig. 3.

The test rig includes a solid–liquid two-phase flow circuit (1, 5 and 9), a water circuit (5, 6, 7 and 9) and a high speed photograph measurement system (16, 17 and 18). All the particles are restricted in the solid–liquid two-phase flow circuit by filter 6. Specially, the test rig mainly consists of a double blade pump (1), a water tank (7), an electromagnetic flow meter (3), a feed hopper (10), an electric motor (13), a torque meter (14), a high speed camera (17), two valves and pressure transmitters at inlet and outlet.

The pressure at suction and discharge is measured by inlet pressure transmitter and outlet pressure transmitter respectively. The flow rate is recorded by the electromagnetic flow meter. An electric motor whose maximal power is 7.5 kW is used to drive the pump in the test. A torque meter is used to measure the torque and the rotational speed of the pump.

A high speed camera is used to capture the movement of coarse particles in the double blade centrifugal pump to obtain the particle passing pump time and the image of the moment when particles hit the tongue.

In the test, particles are put into the circuit and recycled by the feed hopper. To reduce the gas in the circuit, the three-way tube Ⅲ is used to change the water flow direction.

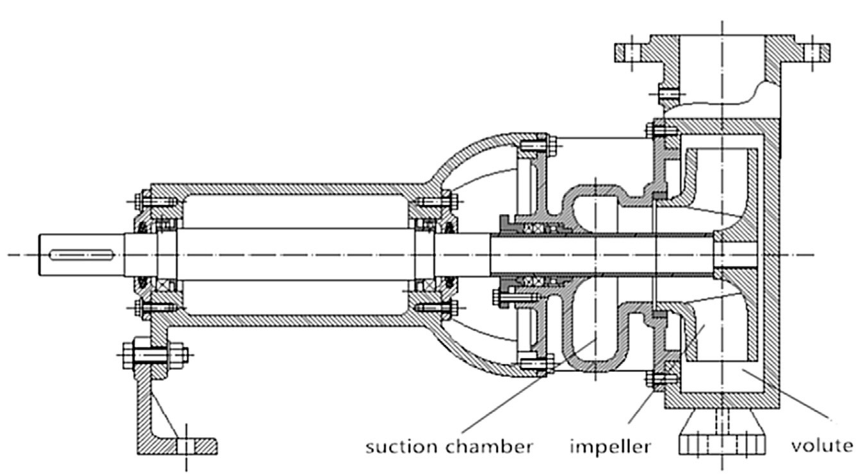

Fig. 1. Structure of double blade model pump.