Numerical simulation of solid-liquid two phase flow on a rotating disk

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Abstract. Currently, sediment abrasion is becoming more and more serious in hydraulic machinery. In this paper, the internal flow field of solid-liquid two phase was analyzed. In order to improve the uniformity of solid distribution on the surface of rotating disk, the solid particle diameter and inlet concentration need be reduced. With the increasing of the particle diameter and concentration, the difference of solid volume fraction increases between the rotation center and edge of disk. Particles’ velocity of impact the disk’s surface linearly increases along the increasing disk radius. The impact velocity at the outer edge of the disk is maximal, reaching over 40m/s. The change of impact velocity at each radius is not obvious with the variety of particle diameter.

1. Introduction

Research and development of wear resistant material with good performance (including base material and protective materials) is an efficient protection measure adopted at present to reduce the wear of hydraulic machinery. It is also a focus of concern at home and abroad. Sediment abrasion is inevitable in hydraulic machines which operating in rivers. The sediment concentration of Yellow River is the most abundant in our country, and its high sediment concentration is rare in the world. Since most large and medium-sized hydropower stations and pump stations were built on the Yellow River early, the hydraulic machinery was seriously worn. Therefore, the study of sediment abrasion in China started from the Yellow River. Subsequently, due to the severe wear and tear of the Gezhouba Dam hydropower station and the construction of the Three Gorges project, the discussion of the silt erosion of hydraulic machinery on the Yangtze River has been paid much attention. In recent years, with the development of hydropower units, the abrasion caused by small sediment concentration has attracted people's attention. In the feasibility study or preliminary design stage, it is necessary to study on the rivers’ sediment status in this kind of project and the damage on the prototype.

The solid-liquid two-phase flow system composed of solid particles and water, which is the study content of this paper. Compared with clean water, the solid-liquid two-phase flow is more complicated. In the present study, water is the liquid phase and the carrier of the solid phase. It is a viscous fluid. The solid phase, sediment particle has the characteristics of certain size, concentration, particle shape and density and so on. The fluid phase and the solid phase have different velocity distribution fields respectively. Therefore, in order to solve the problem of erosion and abrasion of sediment, it is the foundation of the research to know deeply the characteristics of sediment laden flow field. Firstly, based on the k-ε turbulent flow model, the macroscopic flow field in the rotating disk is computed.
The motion state of particles is analyzed by Euler model, and the movement parameters such as scouring speed and erosion angle of particles washing the rotating disk surface are obtained.

A common liquid solid two phase flow is a mixture of liquid and solid phases. In physics, the two-phase flow is clear, but it is still difficult to solve the two-phase flow by using mathematical tools. In the numerical simulation of liquid-solid two-phase flow in rotating disk, the hypothesis is as follows:(1) The time averaged motion of a flow field in the rotating disk is steady flow.(2) The fluid in the rotating disk is continuous and incompressible Newton fluid.(3) The particles are composed of spherical particles with the same size and rarefied, so that the interaction between particles can be neglected.(4) Particle phase and fluid phase without mass transfer, the interaction between particle phase and fluid phase only considering the additional mass force, drag force and Saffman force. Pressure gradient force, Magnus force and so on are neglected.

2. Numerical simulation of fluid phase on the rotating disk
Based on the above hypothesis, the numerical simulation of solid-liquid two-phase flow is carried out based on rotating disk. The motion of the solid particle phase is based on the fluid motion, and the limiting case of the solid-liquid two-phase flow is a single fluid flow, i.e., the particle size or particle concentration is zero. Therefore, the flow field of single-phase flow is solved, and then the movement process of two phase flow is solved.

2.1. Three dimensional model
In this paper, a 3-D model of the wear region on the rotating disk wear test rig is first carried out, as shown in figure 1. The entry is appropriately extended of the 3-D model. In this paper, the change of water flow or sediment parameters on the working surface of rotating disk, that is, toward the inlet surface of the water, is studied. The rotating disk working surface is hereinafter referred to as the rotary disk surface.

2.2. Computational domain and boundary conditions
The model inlet boundary is the velocity inlet of corresponding velocity 2.05m/s. The Reynolds number at the entrance of the rotating disk is turbulence, so the standard k-ε turbulence model is adopted for computation. In the iterative computation, the residuals of continuity, turbulent kinetic energy and turbulent dissipation rate are monitored. At the same time, monitor the flow change of the outlet. The criterion for setting iterative convergence is $10^{-5}$. A tetrahedral unstructured mesh is used to divide the 3D model.

![Figure 1. Three dimensional modeling and grid pattern of rotating disk wear test rig](image)

3. Analysis of single-phase flow computational results
Figure 2 shows the velocity profiles of different sections inside the rotating disk (distance to the rotating disk surface of $f_1$, $f_2$, $f_3$ are respectively 10mm, 20mm, 30mm), and the color code’s unit in the figure is m/s. As seen from the diagram, the velocity of water is uniformly distributed on the surface of the rotating disk, and the water rotates along the surface of the disk. The water velocity
increases along the radius. There is a swirl in the exit of the rotating disk, mainly due to the asymmetry of the flow path. In the stiffened panel region, the flow is complicated and is driven by the rotating disk with high speed rotation. The surface of the stiffened panel is impacted leading to backflow and vortex, and the flow pattern is poor. On the rotating disk surface, the flow maximum velocity is 55m/s. In the solid region away from the surface of the disk, the flow velocity decreases gradually, the minimum velocity is about 1m/s, and the flow regime is poor.

Figure 2. Velocity distribution on different sections inside the rotating disk

4. Analysis of solid-liquid two-phase flow on the rotating disk

4.1. Initial conditions and boundary conditions of particle phase

In the computation process, the particles are evenly distributed to all the computational grids according to the mesh volume. A certain number of particles are represented by a computational particle. Each particle has its own moving track, and does not interfere with each other.

Euler model is selected for solid-liquid two-phase flow. Under the rated conditions, the two-phase flow in the turbine is simulated when the particle volume concentration is \( C_v = 2.5\% \), the particle density is 2800kg/m\(^3\), and the particle diameter is 0.15mm.

The velocity inlet and outflow boundary conditions are used.

4.2. Analysis of calculation results of different particle diameters

Different sizes of solid particles affect the speed, direction and distribution of solid particles on the surface of rotating disk. Figures 3, 4 and 5 show the distributions of solid particles with different diameters 0.1mm, 0.15mm and 0.2mm on disk surface and surfaces with different distances from the disk. It can be seen from the figure that with the same particle diameter, the volume fraction of solid is higher in the smaller radius region of the disk surface, and the volume fraction of solid is lower in the larger radius region. In the outlet pipe, the area of low volume fraction of solid increases, and the
particle concentration at the bottom of the pipeline is high. In the stiffened panel region, the degree of solid particle deposition increases on the stiffener surface.

**Figure 3.** Solid particle distribution on different surface of $C_v=2.5\%$-$d=0.1\text{mm}$

**Figure 4.** Solid particle distribution on different surface of $C_v=2.5\%$-$d=0.15\text{mm}$
In general, with the increasing of particle diameter, solid concentration increases at the region with high solid volume fraction, and solid concentration decreases at the region with low solid volume fraction. The difference of solid volume fraction becomes larger between the rotation center and the edge of the disk.

Figure 6 shows the velocity variations of particle impacting on the disk surface along the radius with different particle diameters. It can be seen from the figure that with the increase of the radius, the velocity of particles impacting on the disk surface increases linearly, and the impact velocity at the outer edge of the disk is maximal, reaching over 40m/s. The change of impact velocity at each radius is not obvious with the variety of particle diameter.

Figure 5. Solid particle distribution on different surface of \( C_v = 2.5\% - d = 0.2\text{mm} \)
Figure 7 shows a streamline diagram of the liquid and solid phases in the rotating disk when the diameter of the particles is different, in which the unit is m/s. As seen from the diagram, the flow of water or sediment particles only flows regularly along the surface of the rotating disk and flows outward from the center to the outer edge along the disk surface. In other regions of the rotating disk, the flow is disordered, especially in the ribs, where vortices are produced and the flow is asymmetric. In the outflow pipe, the fluid and solid particles also produce an obvious vortex.

5. Conclusions
In this paper, the k-ε model is used to analyze the single-phase flow field inside the rotating disk. Then, based on the Euler model, the variation law of solid-liquid two-phase flow field in rotating disk with different particle diameters and different particle inlet concentrations is discussed. A three-dimensional solid liquid two phase flow model of rotating disk is established. The inside two-phase flow field of solid-liquid on a rotating disk was analyzed. In order to improve the
uniformity of solid distribution on the surface of rotating disk, the solid particle diameter and inlet concentration need be reduced.

With the increasing of the particle diameter and concentration, the difference of solid volume fraction increases between the rotation center and edge of disk.

Particles’ velocity of impact the disk’s surface linearly increases along the increasing disk radius and the impact velocity at the outer edge of the disk is maximal, reaching over 40m/s. The change of impact velocity at each radius is not obvious with the variety of particle diameter.

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**References**
[1] Bedecarrats J and Strub F J 2009 Appl. Therm. Eng. 29 1166-72
[2] Bobzin K, Oete M, Linke T F and Malik K M J 2016 J. Therm. Spray. Techn. 25 365-74
[3] Ghiban B, Safta C, Ion M, Crangasu C E and Grecu M J 2017 Energy Procedia, ed A Anton, et al. pp 75-82
[4] Ji Z, Bao L, Wang H and Chen R J 2017 Mater Lett. 207 21-4
[5] Peng G, Wang Z, Xiao Y and Luo Y J 2013 Eng. Fail Anal. 33 327-35
[6] Shan X, Yu G, Yang C, Mao Z and Zhang W J 2008 Ind. Eng. Chem. Res. 47 2926-40
[7] Wu Y, Jia S, Wang S, Qing Y, Yan N, Wang Q and Meng T J 2017 Chem. Eng. J. 328 186-96
[8] Zhang D, Zhao P, Zhao W, Luo Y and Xie Y J 2014 Adv. Cond. Matter. Phys.
[9] Zhang J, Kang J, Fan J and Gao J J 2016 J. Loss Prevent Proc. 43 438-48
[10] Zhang Y, Tang J, Guo W and Zhang K J 2016 China Mech. Eng. 27 2797-801
[11] Zhang Z, Chen L, Wang Z and Cui T J 2016 New Chem. Mater. 44 230-2
[12] Zhang Z, Nie S, Yuan S and Liao W J 2015 Tribol. T. 58 1096-104
[13] Zhou Q, Li N, Chen X, Xu T, Hui S and Zhang D J 2009 Int. J. Impact Eng. 36 1156-71
[14] Zhu R, Shao S, Deng M and Yan J J 2016 New Chem. Mater. 44 218-21