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Procedia Engineering 31 (2012) 87 – 91
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Advances in Computational Modeling and Simulation

Solid-liquid Two-phase Flow Numerical Simulation around Guide Vanes of Mixed-flow Water Turbine

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Abstract

Based on the N-S control equation and κ-ε-Ap turbulent model, the solid-liquid two-phase flow field around the guide vanes of a mixed-flow water turbine was simulated. The solid-liquid two-phase flow characters around the guide vanes were analyzed on the design work condition with different volume fraction and particles diameter of solid phase. The effects of the solid particles diameter and volume fraction on the flow around the guide vane are discussed, based on which the prediction and analysis of abrasion and cavitation properties on the guiding device were given. The prediction results were identical with the test date, which can provide reference on the abrasion prediction and optimal design of guide vanes.

Keywords：Water turbine; guide vane; Solid-liquid two-phase flow; Numerical simulation.

1. Introduction

Hydropower resources are very rich in china, using of water power to generate electricity plays a very important position in the national economy. For various reasons, sediment content is very high in many rivers in china.especially ,Yellow River's transporting sediment in annual is the most all over the world, up to 16 billiont[1]. As the sediment greater, wear and tear on the turbine is very serious, which has great impact for the normal operation of hydropower stations[2]. Francis turbine hydraulic design of guided components plays an important role in turbine performance. the two-phase media Erosion-Corrosion ,it is

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doi:10.1016/j.proeng.2012.01.995

closely related to turbine flow pattern in the sediment water flow[3].Therefore, through comprehensive analysis and numerical simulation for coupled flow of turbine conductivity components to investigate flow principles of sediment-water two-phase flow in conductivity components of hydraulic turbine, master the law of motion of two-phase flow, it is necessary to predict and mitigate as well as solute to passage components wear .This paper, the vanes and guide vanes as a link coupling the overall consideration, based on the N—S equation , and using κ -ε -Ap turbulent model,unstructured tetrahedral network and SIMPLE algorithm to make numerical for its internal flow[4].analyzing its internal flow mechanism, exploring and predicting where the law of wear and cavitation.

2. Basic Equations

In the Eulerian coordinate system to establish solid-liquid two-phase flow equations of motion.

Liquid phase continuity equation

$$\frac{\partial \Phi_L}{\partial t}+\frac{\partial}{\partial x_i}\left(\Phi_L U_i\right)=0 \qquad (1)$$

Solid-phase continuity equation

$$\frac{\partial \Phi_S}{\partial t}+\frac{\partial}{\partial x_i}\left(\Phi_S V_i\right)=0 \qquad (2)$$

Liquid momentum equation

$$\frac{\partial}{\partial t}\left(\Phi_L U_i\right)+\frac{\partial}{\partial x_k}\left(\Phi_L U_i U_k\right)=-\frac{1}{\rho_L}\Phi_L\frac{\partial P}{\partial x_i}+\nu_L\frac{\partial}{\partial x_i}\left[\Phi_L\left(\frac{\partial U_i}{\partial x_k}+\frac{\partial U_k}{\partial x_i}\right)\right]-\frac{B}{P_L}\Phi_L\Phi_S\left(U_i-V_i\right)+\Phi_L g_i \qquad (3)$$

$$\frac{\partial}{\partial t}\left(\Phi_L U_j\right)+\frac{\partial}{\partial x_k}\left(\Phi_L U_j U_k\right)=-\frac{1}{\rho_L}\Phi_L\frac{\partial P}{\partial x_j}+\nu_L\frac{\partial}{\partial x_k}\left[\Phi_L\left(\frac{\partial U_j}{\partial x_k}+\frac{\partial U_k}{\partial x_j}\right)\right]-\frac{B}{P_L}\Phi_L\Phi_S\left(U_j-V_j\right)+\Phi_L g_j \qquad (4)$$

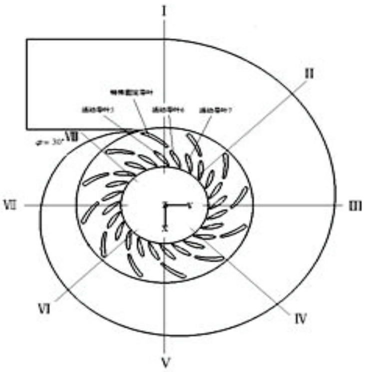
Equation (3) and (4) are respectively i and j projections of fluid momentum equations, Solid-phase momentum equation.

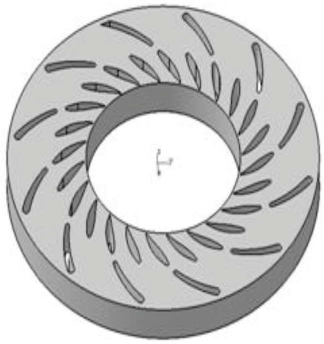
$$\frac{\partial}{\partial t}\left(\Phi_S V_j\right)+\frac{\partial}{\partial x_k}\left(\Phi_s V_i V_k\right)=-\frac{1}{\rho_s}\Phi_s\frac{\partial P}{\partial x_i}+\nu_s\frac{\partial}{\partial x_k}\left[\Phi_s\left(\frac{\partial V_i}{\partial x_k}+\frac{\partial V_k}{\partial x_i}\right)\right]-\frac{B}{\rho_s}\Phi_L\Phi_s\left(V_i-U_i\right)+\Phi_s g_i \qquad (5)$$

where, U_i and V_i are the speed of the liquid and solid components, ρ is the phase material density, v is kinematic viscosity coefficient of phase material, P is the pressure, gi is the gravitational acceleration component, x_i is the coordinate component, $B = 18(1 + B_0)\rho L\nu L/d^2$ The formula express coefficient of white effect, d is the particle diameter. In order to consider other effect factors except Stokes linear drag effect, the B_0 is introduced. Under normal circumstances, B_0 is not constant . Subscripts: L and S are liquid and solid phase, i, j, k is the tensor coordinates[5].

3. Establish Geometric Model and Divide Grid

A power station HL-001-LJ-550 unit is used as object, geometric modeling is established for the scroll, the fixed guide vanes and guide vanes area.The vanes extend certain torus exports to the unit axis, ignoring the influence of runner on guide vane area [6].3-D diagram is shown in Figure 2, taking the area of fixed vanes and guide vanes, and special areas of fixed guide vanes and guide vanes5, 6, 7 as the specific follow-up simulation objects. As the gap and the angle are small, which may have resulted in dividing grid is unsuccessful.Therefore, the mixed tetrahedral mesh which is broader scope unstructured grid is used as model [7].Which flow channel grids are0. 360579 million in vanes and guide vanes , the generated grids shown in Figure 3.





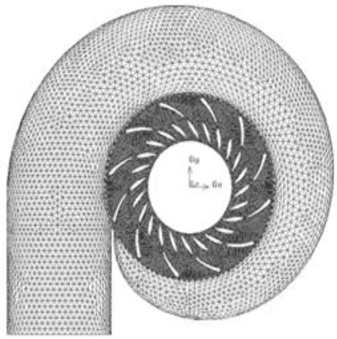


Figure 1 Two-Dimensional Model   Figure 2 Three-Dimensional Model   Figure 3 The dividing mesh

4 . Results and Analysis

Selecting solid-liquid two-phase flow of water and sand as the medium. Sand density is 2650kg/m^3, the volume fraction of solid phase is 0.76%, the size of particle is 0.08mm, simulated conditions is the optimal condition.

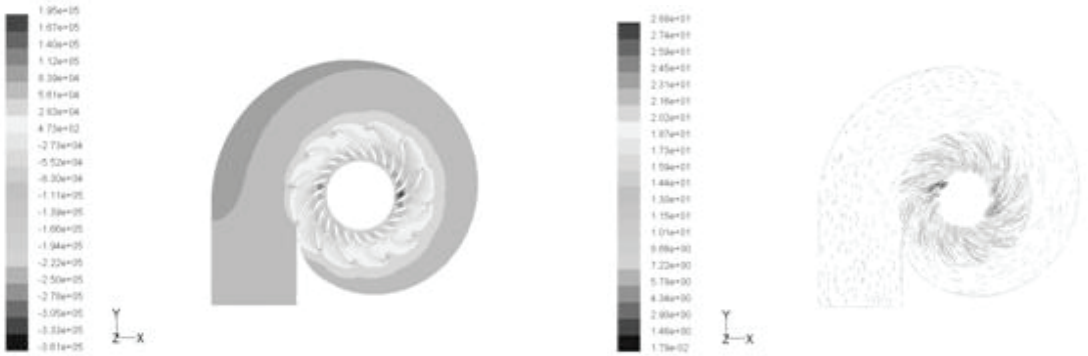


Figure 4&5 The pressure distributing and the velocity vector of the middle section

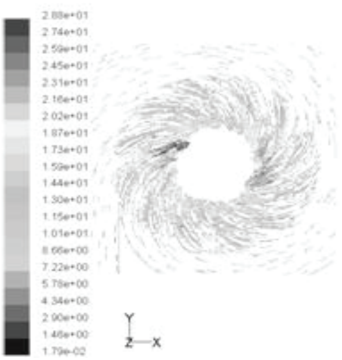


Figure 6 The velocity vector of sediment concentration the integrant Guide Vane

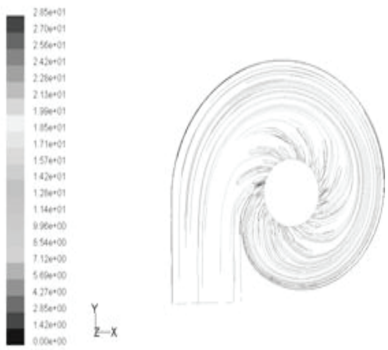


Figure 7 The solid trace of the middle section

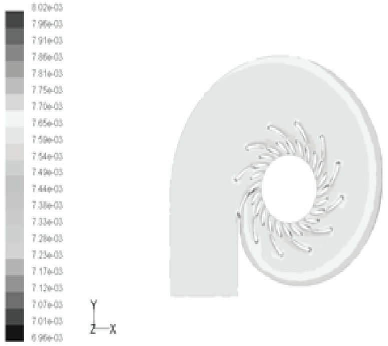


Figure 8 The volume distributing of the middle section

According to the pressure distribution in the section of conveying containing sabulous water (figure 4), velocity vector chart (figure 5), solid phase mark chart (figure 7), solid phase concentration distribution (figure 8) and part of the guide vane velocity vector map (figure 6), we can see, on the one hand, the differences between two phase flow media trends and clear water medium are not significant, pressure and velocity distributions in circumference direction has good symmetry [8], in the guide vane interval pressure from fixed guide vane import to the activity export has decreased along the radial, and velocity vector has increased[9]; On the other hand solid grain has a big difference to the water turbine water deflector in the flow field.

Because two-phase flow has great influence on the guide vane's head and the role of side wall more than clear water in the flow field of liquid in the movement in the process which lead to obviously taking off in the guide vane, producing vortex flow and having smaller impact off flow between the fixed guide vane inlet and activities. And some flow of the guide vane area changes obvious. At the out and the inner side of guide vane, particle collisions angle are larger in the head, then decrease gradually until the guide vane, which shows that a hit to the head loss bigger but the tail is small, so cavitation and erosion of the area intensifies; And in this area the flow situation of the symmetrical guide vane also has worsened. Because the two phase medium flow has increased speed in the guide vane export and kinetic energy is bigger, so the pressure is smaller, thus it's easy to occur cavitation phenomenon, cause local the flow of the disturbance, and at the same time cavitation erosion of components caused by the cavitation phenomenon will cause damage to the wall, make a big loss which caused by solid particles impacting the wall , namely the cavitation erosion and wear the joint action of components, the loss caused by more than they separate the loss caused by the sum function; The same velocity and acceleration are big parts wear to occur.

5. conclusion

1) When containing two phase flow sediment flow through the water turbine parts internal, the flow situation will change.

2) To guide vane head and side wall parts change is more apparent, stress field, velocity field distribution are different degree of change. In particular the guide vane fixed head and face near the head position, the head and face the guide vane activities and face to the rear of the area near the head belongs to wear serious regional. So in the design must be considered in the parts of the corresponding should strengthen treatment. According to two phase flow condition of the water turbine, optimize design guide vane, rational improve fixed diffuser's size, shape, settling angle , correct the airfoils of the activities guide vane and optimize the opening position and tie-in relationship between fixed diffuser and activities diffuser, making it adapt to its exports to water in case basically circumference direction distribution, adjust activities diffuser the placement of settling Angle and import, reduce the guide vane head loss, reduce water taking off after water turbulence flow in guide vane area, so as to improve the efficiency of the turbine.

Acknowledgments

The authors graciously acknowledge the funding of Ph. D. Innovation Programs Foundation of Lanzhou University of Technology (Grant No. 51079066) and Natural Science Foundation of China (Grant No. 1106ZGA062) to this project.

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