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To cite this article: X F Ge et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 163 012099

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Study on pressure drop and cavitation performance of rotating disk at different speeds

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Abstract: Cavitation is harmful to hydraulic machinery and equipment, which often reduces the service life and efficiency of equipment. In this paper, cavitation is further studied by studying the cavitation of the rotating disc. In this paper, the generation of the cavitation bubble in the rotating disc is numerically simulated, and the location of the low pressure zone and the relationship between the number and the speed, when the rate is less than 2000r/min, fitting the speed and minimum pressure, the fitting relation is a linear curve; the shape of the bubble coming out of the cavitation source and the position of the bubble on the rotating disk. Verified by the field test, cavitation source side of the metal and the specimen produced erosion by long time cavitation.

1. Introduction

Cavitation is a kind of vaporization phenomenon, and it is also a complex fluid dynamic phenomenon which is unique to the liquid [1-3]. At present, cavitation has not yet unambiguously defined, and the cavitation phenomenon is generally understood by simply describing its characteristics. When the water pressure in the liquid is lower than the critical value of the empty words, the liquid is vaporized and the vacuoles in the liquid will grow rapidly into the vacuolar flow. When the vacuoles flow to the high pressure zone, the vacuolar development terminates and collapses at a faster rate. It can be seen that the cavitation in the flow field is a discontinuity of the liquid, which includes three stages of vacuolization, development and collapse.

The basic features that can be summarized from the above description can be summarized as follows:

- Cavitation only appears inside the liquid.
- Cavitation is caused by the pressure drop in the liquid (in the numerical simulation, the critical pressure is defined by the saturated vapor pressure of the liquid at the corresponding temperature, but in fact there is a certain deviation between the cavitation primary pressure and the liquid saturation pressure), we can control the liquid pressure to control the occurrence of cavitation.
- Cavitation is a kind of hydrodynamic phenomena including vacuolization, development and collapse.

As mentioned above, when the cavitation occurs, a large transient pressure is often generated during the collapse of the bubble, so that the voids will cause serious damage such as material damage on the
surface of the overcurrent component. Bin Ji [4-5] study the cavitating vortical flow structure around hydrofoil., Tan Lei study the characteristics of unsteady flow in a centrifugal pump [6-7] and Zhang, Y summarized microscopic interactions between cavitation bubbles and particles in silt-laden flow. In this paper, cavitation is further studied by studying the cavitation of the rotating disc.

2. The introduction of rotating disc

Rotary disc test can be used to simulate the cavitation and the damage to the metal material, and the metal material which is made into a circular specimen mounted on the rotating disc. The rotating disc with a transparent cavitation hole is mounted in a sealed container, and by changing the rotational speed of the disc, the high-speed rotation of the disc produces a higher water velocity, resulting in a pressure drop. The liquid water is changed into bubble, and the resulting bubble with the flow of water jet in the metal specimen which near the cavitation. In this paper, the generation of the cavitation bubble in the rotating disc is numerically simulated, and the location of the low pressure zone and the relationship between the number and the speed, the shape of the bubble coming out of the cavitation source and the position of the bubble on the rotating disk. Verified by the field test, cavitation source side of the metal and the specimen produced erosion by long time cavitation. The rotating disc is shown in figure 1.

![rotating disc device](image)

![rotating disc](image)

![local enlarged drawing](image)

![round specimen](image)

Figure 1. The rotating disk and test specimen

3. Numerical simulation of cavitation

The study of cavitation is mainly divided into two parts: experimental study and numerical simulation. Compared with the experimental study, numerical simulation has the advantages of short cycle and low cost, and is not affected by the experimental site and equipment which is the effective means of the cavitation

In this paper, the simulation of cavitation is carried out based on ANSYS CFX. CFX is used to process the conversion process between gas and liquid by simplified Rayleigh-Plesset equation. The Rayleigh-Plesset equation solves the relationship by defining a spherical voided characteristic radius \( R_B \) in the liquid and the pressure \( p \) which is defined for one point away from the bubble in the liquid. The equation is as follows:

\[
\frac{p_B(t) - p(t)}{\rho_l} = R_B \frac{d^2 R_B}{dt^2} + \frac{3}{2} \left( \frac{dR_B}{dt} \right)^2 + \frac{4\nu}{R} \frac{dR_B}{dt} + \frac{2\gamma}{\rho_l R_B} \tag{1}
\]

Among them, \( p_B \) is the pressure inside the bubble which generally assumed as the vaporization pressure of the temperature; \( \nu \) is the kinematic viscosity; \( \gamma \) is the surface tension. In the calculation, it is assumed that the voids are not latent heat in the process of evolution, and the fluid is not viscous.
while ignoring the surface tension between the vapor and the liquid and the second derivative of the time. The equation (1) can be simplified as:

$$\frac{dR_B}{dt} = \sqrt{\frac{2}{3}} \frac{p_B(t) - p(t)}{\rho_l}$$  \hspace{1cm} (2)

In the calculation, assuming that the vacuolar volume fraction $\tilde{\phi}_v$ is composed of $N$ vacuoles, the vacuolar volume fraction expression is

$$\tilde{\phi}_v = NV_B = \frac{4}{3} \pi R_B^3 N$$  \hspace{1cm} (3)

CFX defaults to the Zwart-Gerber-Belamri cavitation model, where the source region consists of the evaporation rate $m_v^+$ and the coagulation rate $m_v^-$ between the two phases per unit volume, just as:

$$m_v^+ = m_v - m_v^-$$  \hspace{1cm} (4)

$$m_v^+ = F_{vap} \frac{3r_{nuc}(1 - \tilde{\phi}_v)\rho_v}{R_{nuc}} \sqrt{\frac{2}{3}} \frac{\text{Max}(p_v - p, 0)}{\rho_l}$$  \hspace{1cm} (5)

$$m_v^- = F_{cond} \frac{3r_{nuc} \tilde{\phi}_v \rho_v}{R_{nuc}} \sqrt{\frac{2}{3}} \frac{\text{Max}(p_v - p, 0)}{\rho_l}$$  \hspace{1cm} (6)

Among them, $F_{vap}$ is the vaporization coefficient, in different states with different sizes, which Shen and Gerber through the verification of the liquid get that in the vaporization, the constant $F_{vap}$ is 50; and when the bubble occurs liquefaction, the constant $F_{cond}$ is 0.01, liquefaction pressure $\rho_v$ is 3540pa.

In this paper, the grid of rotating disk is structured with grid, the model is divided into blocks, and the trial disk is part of the rotation domain. It has periodic characteristics and periodic meshing. In this paper, CFX is used to calculate the inlet boundary condition as the total pressure inlet. When the cavitation model is added, the inlet volume is 0 and the liquid phase is 1; the exit boundary condition is the mass flow outlet; Wall boundary conditions for the non-slip surface; for the trial disk, we need to set the internal interface between the water, because the trial disk for the rotation domain. The import and export interface is set to static and dynamic interface and defined as Frozen Rotor mode, there is a need for GGI grid splicing technology to transfer data between interfaces. In order to reduce the calculation error and ensure the convergence of the calculation, the first single-phase flow field is taken in the calculation, and the cavitation model is loaded into the cavitation two-phase flow.

During the process of the numerical simulation with the same flow under different pressure conditions, the minimum pressure of the disc rotation position shown in figure 2
It can be seen from figure 2, the minimum pressure in the rotating disc appears in the cavitation source when the flow and pressure are constant during the cavitation experiment of the rotating disc. With the increase of the rotational speed, when the rate is 2000r/min, the bubbles are generated inside the cavitation source and escape from the cavitation source. The number of bubbles becomes small while is far away from the cavitation source, the more bubbles are destroyed at the round specimen near the cavitation source. As the speed increases, the number of cavitation bubbles increases.

Minimum absolute pressure of different rotate speeds list in Table 1, when the rate is less than 2000r/min, fitting the speed and minimum pressure, the fitting relation is a linear curve, the fitting equation is $y = -72.923x + 148331$. The fitting curve is shown in figure 3.
Table 1. Minimum absolute pressure of different rotate speeds

| n (rpm) | Pabs (pa) |
|---------|-----------|
| 400     | 114600    |
| 800     | 98310     |
| 1200    | 58930     |
| 1600    | 28740     |
| 2000    | 3540      |
| 2500    | 3540      |
| 3000    | 3540      |

Figure 3. Minimum absolute pressure - rotate speed curve graph

4. The comparison of the field experiment

On the basis of numerical simulation, we also carried out experiments on rotating disk experiment platform. In the experiment, the pressure of the whole experiment device is controlled and the flow rate is not changed. The rotational speed of the rotating disc is changed by adjusting the control cabinet from 0 to 3000r / min, and the cavities are generated when the rotational speed is 2500r / min. The number of vacuoles, and the form of movement that produces vacuoles are studied. Figure 4 for the experimental shot with the resulting bubble.

(a) Experimental camera image  (b) Local enlarged drawing  
(c) Numerical solution diagram  (d) Local enlarged drawing

Figure 4. The picture cavitation bubble

The cavitation bubble in the rotating disk rotation when the speed was 2000rpm showed in figure 4, when the speed is 0, there is no bubbles, until the speed of 2500r / min, the bubble is the most obvious. The bubbles are generated inside the cavitation source and escape from the cavitation source. The
number of bubbles becomes small while is far away from the cavitation source, the more bubbles are destroyed at the round specimen near the cavitation source. As the speed increases, the number of cavitation bubbles increases. This is the result of our numerical simulation. At the time of simulation, the pressure in the cavitation cavity is the lowest and the bubble is easy to produce. With the increase of the rotational speed, the number of bubbles increases and the bubbles are generated from the cavitation source and escape, next to the round specimen at the collapse of the experimental and numerical simulation results consistent.

5. Conclusion
In this paper, the numerical simulation results are verified by experiments. The rotating discs control the flow and pressure during the rotation process. When the rotational speed of the rotating disc is changed. The low pressure zone appears inside the cavitation source. when the rate is less than 2000r/min, fitting the speed and minimum pressure, the fitting relation is a linear curve, as the rotational speed reaches 2000rpm, the cavities generate cavitation bubbles, and cavitation bubbles produce and escape at the cavitation source. There are more bubbles near the cavitation source, less bubbles away from the cavitation source, and bubbles in the circular test near the cavitation source were destroyed. As the speed increases, the number of cavitation bubbles increases and the number of bubbles is proportional to the speed.

Acknowledgments
The research work was supported by the following funding: The Open Research Subject of Key Laboratory of Fluid and Power Machinery, Ministry of Education, Xihua University(szjj2015-042); The Central Universities fundamental research funds (2015B02814); the National Natural Science Foundation of China (51339005); the Key Project of Yunnan Power Grid Co. Ltd. (YNYJ2016043).

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