The Influence Analysis of Expansion Angle and Internal Fluid Cavitation Phenomena for Zoom Nozzle

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Abstract—The cavitating water jet is a new type jet with great potential and good efficiency, which has been applied widely in rock crushing, oil drilling, wastewater degradation, industrial cleaning and so on.Cavitating water jet cleaning technology was caused the attention in these years for good cleaning quality and cleaning speed, no environmental pollution, no corrosion of cleaning material etc. The simulation model of zoom nozzle was established in this paper. The numerical simulation of internal fluid for the zoom nozzle was completed with the different expansion angles by the fluent software. The results showed that the pressure near the transition area of the cylindrical section is so low that it's easy to form the cavitation phenomenon; and in the different nozzle expansion angle, the change tendency of the fluid gas content is consistent; and with the nozzle expansion angle increasing, the distance between that emergence point of maximum cavitation rate and nozzle cylindrical section decreases continuously.

Keywords-cavitating jet; zoom nozzle; cavitation; expansion angle; simulation

I. INTRODUCTION

Cavitation is a process of the formation, development and breaking on the "bubbles" and gas bubbles by local pressure reduced in the liquid. Studies show that when the bubbles collapse in the liquid, inside the minimal space around the bubble will produce instantaneous high temperature (about 5200K) and high pressure (50MPa or more) [1, 2]. So it may cause damage to the hydraulic and flow components, and makes a great noise. However, Water jet technology [3, 4], super-cavitation pump [5] and super-cavitation torpedo [6] technology was put forward due to cavitation theory. The cavitating water jet is a new type jet with great potential and good efficiency and water jet technology was developed in the 20th century. So far, it has been widely used in rock crushing, oil drilling, wastewater degradation, industrial cleaning [7-9] and other areas.

Marine resources have become the focus of international competition. The Marine environment is directly related to national security and sustainable development. Therefore, the Marine science of all the coastal developed countries is regarded as a priority development of strategic areas. In order to better access to Marine resources, a lot of ships and Marine structures are required (such as oil platforms, offshore oil facilities, etc.). When these ships and Marine structures work in the long time, all kinds of dirt and aquatic organisms in the water will be attached to the hull surface. These fouling increased the ship sailing resistance, leading to the increase in fuel consumption, and bringing certain security hidden danger, so you need to clean on a regular basis.

An ocean-going freighter was coat antifouling paints only once, which was maintained in June. The following year in August, the bottom was attached to a large number of sea creatures, when mooring 28 days in Sicily, Italy port. When it was in return, speed was reduced from section 18 to section 13, sailing time increasing by more than 10 days, fueling more than 500 tons of fuel consumption. In Xiamen area, due to improper antifouling coating of a boat, the hull fouling organisms was up to 17 kg/m2, which making speed reduce by 30%. Cooling water piping inner surface of Dalian power plant attached a lot of sea creatures, which making pipe diameter reduced, not only influencing the normal water supply, but also often causing accidents, wasting a lot of manpower and clear; Marine fouling organisms can also affect the tactical performance of some weapons: if non trigger attached a lot of sea creatures, it will cause the fuze failure, mine aggravating and sinking, changing the original depth setting standards; Navigation facilities and prevention department of the camel are also regularly removed fouling organisms, or causing accidents and loss.

Cavitation water jet cleaning technology has good cleaning quality and cleaning speed, no environmental pollution, no corrosion of cleaning material etc., which gradually causes the attention of people. The method of marine fouling organisms Dominated by cavitation jet, which is a new kind of Marine services equipment manufacturing industry, and belongs to high and new technology application in ocean engineering direction, and is an important part of economic growth point in blue China's emerging economy. With the increasing of China's maritime technology, such as maritime exploration and production activities more frequent, marine fouling organisms' cavitation cleaning will have broad market space and industrialization prospect. It is estimated that the cost used to prevent marine fouling was at least $1.4 billion a year in the aspect of gulf in the worldwide. So we must prevent deposition in various sea creatures, coating with protective paint in the hull or Marine facilities surface usually, but the prevent measures always have a certain timeliness, which is inevitably and must use the appropriate method to clean the fouling organisms. Using cavitation jet cleaning sea creatures, not only for our country to reduce energy consumption of several hundred million dollars each year from ships cost, but also because of its own method of energy conservation and environmental protection, greatly reducing the energy consumption on our country sea biological fouling cleaning and Marine pollution [10,11].

The mechanism is let the high pressure water jet out through various shapes of nozzle after its pressure increased by the high pressure water pump, and then formed great penetrating power of high-speed water jet which can be used to achieve cleaning, cutting and other purposes. However, when the local pressure in the nozzle drop to the saturated vapor pressure of water, air bubbles will be generated inside the fluid and formed cavitation jet. While the cleaning effect is determined by the cavitation rate, and the cavitation scale is influenced by the nozzle geometry structure directly besides pressure and flow rate. This article studied the influence for the expansion angle of the zoom nozzle to the nozzle internal fluid cavitation phenomenon by the nozzle physical and simulation model based on the advanced computational fluid dynamics software Fluent and the numerical simulation method [12].

II. MATHEMATICAL MODEL AND PHYSICAL MODEL

A. *Simulation dynamic equation*

Continuity equation and motion equation are the basic equations used to describe the fluid motion. And the continuity equation expression of incompressible fluid in rectangular coordinate system could be written as follows:

$$\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}=0 \tag{1}$$

N-S equation is used to describe the viscous fluid movement and its expression in the space rectangular coordinate system as follows:

$$\begin{aligned} &X-\frac{1}{\rho}\cdot\frac{\partial p}{\partial x}+\eta\left(\frac{\partial^2 v_x}{\partial x^2}+\frac{\partial^2 v_x}{\partial y^2}+\frac{\partial^2 v_x}{\partial z^2}\right)=\frac{dv_x}{dt}\\ &Y-\frac{1}{\rho}\cdot\frac{\partial p}{\partial y}+\eta\left(\frac{\partial^2 v_y}{\partial x^2}+\frac{\partial^2 v_y}{\partial y^2}+\frac{\partial^2 v_y}{\partial z^2}\right)=\frac{dv_y}{dt}\\ &Z-\frac{1}{\rho}\cdot\frac{\partial p}{\partial z}+\eta\left(\frac{\partial^2 v_z}{\partial x^2}+\frac{\partial^2 v_z}{\partial y^2}+\frac{\partial^2 v_z}{\partial z^2}\right)=\frac{dv_z}{dt} \end{aligned} \tag{2}$$

The standard k-ε equation model was adopted Because of high turbulent jet flow field. In this model, k and ε are two basic unknown parameters—turbulence kinetic energy and the diffusion rate, with the corresponding transport equation is:

$$\begin{aligned} &\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(u+\frac{u_i}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]\\ &\quad +G_k+G_b-\rho\varepsilon-Y_M+S_k \end{aligned} \tag{3}$$

$$\begin{aligned} &\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon u_i)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(u+\frac{u_i}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]\\ &\quad +C_{1\varepsilon}\frac{\varepsilon}{k}(G_K+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \end{aligned} \tag{4}$$

Where G_k is the generation of turbulent kinetic energy caused by the average velocity gradient, G_b is the generation of turbulent kinetic energy caused by the buoyancy, Y_M can be pressed in the turbulent fluctuating expansion contribution, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and $C_{3\varepsilon}$ are the empirical constants, σ_k and σ_ε are the Prandtl numbers corresponding with the turbulent kinetic energy and dissipation rate respectively, S_k and S_ε are the source terms defined by user.

In fluent, the default value is:

$$C_{1\varepsilon}=1.44,\ C_{2\varepsilon}=1.92,\ C_{3\varepsilon}=0.09,$$
$$\sigma_k=1.0,\ \sigma_\varepsilon=1.3$$

B. *Simulation cavitation model*

Schnerr-Sauer cavitation model was used, in which the main phase is the water and the second phase is the water vapor. Local negative pressure zone would be appear due to the high speed of the fluid. When pressure reaches a certain value (-97800 pa), the software appears cavitation phenomenon. The cavitation flow field is constrained by the following equations:

$$\frac{\partial\rho_m}{\partial t}+\frac{\partial(\rho_m u_j)}{x_j}=0 \tag{5}$$

$$\begin{aligned} &\frac{\partial\rho_m u_i}{\partial t}+\frac{\partial(\rho_m u_i u_j)}{x_j}=-\frac{\partial\rho}{\partial x_i}\\ &\quad +\frac{\partial}{\partial x_i}\left[(\mu+\mu_i)\left(\frac{\partial\mu_i}{\partial x_j}+\frac{\partial\mu_j}{\partial x_i}-\frac{2}{3}\frac{\partial\mu_i}{\partial x_j}\delta_{ij}\right)\right] \end{aligned} \tag{6}$$

$$\frac{\partial\alpha_g\rho_g}{\partial t}+\frac{\partial(\alpha_g\rho_g u_j)}{x_j}=R \tag{7}$$

Where t is the time, u is the velocity, ρ_m , ρ_g and ρ are the mixed phase density, the vapor phase density and the liquid phase density respectively, δ_{ij} is the Kronecker number, α_g means the vapor phase volume fraction, μ and μ_i are the mixed-media dynamic viscosity and the turbulence viscosity respectively, R is the transfer rate between vapor phase and liquid phase.

C. Physical model

Fig .1 shows the zoom nozzle's structure. In this figure, all the size parameters take the constants except expansion angle α and the unit is mm, because this paper mainly studies the relationship between expansion angle and internal fluid cavitation phenomenon.

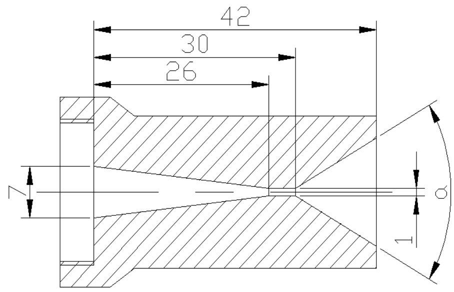

Figure 1. schematic structural view of scaling type nozzle

III. MESHING AND SIMULATION CONDITIONS

A. Meshing

Since the type of scaling nozzle is symmetrical in structure, the two-dimensional axisymmetric modeling directly have been used in the simulation analysis and meshing the computational domain have been used by the Gambit software. When meshed, in order to improve calculation accuracy, the nozzle area before and after the cylindrical section part has carried on the partial encryption processing. Fig .2 is a mesh of two-dimensional nozzle that angle is taken in the expansion at 60.

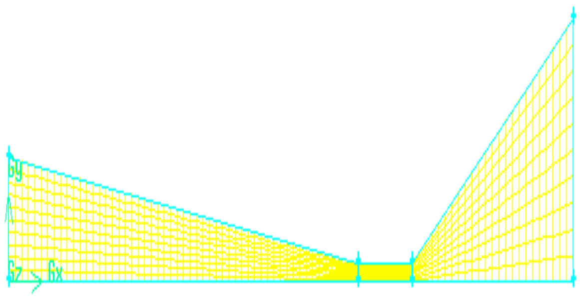

Figure 2. figure mesh

B. Simulation conditions

Two-dimensional double-precision segregated solver has been used for internal flowing field numerical simulation analysis of nozzle. And the parameters were set up as follows:

1) The flow medium choose water-liquid in the database, and its density is 998.2 kg / m3, and its viscosity is 0.001003.

2) Without considering the heat transfer fluids process.

3) RNG k-ε turbulence model standard and a standard wall function close to the wall have used.

4) Inlet and outlet boundary conditions respectively take pressure inlet conditions and conditions for exort.

5) Inlet pressure is 10MP and outlet is of a standard atmospheric pressure.

6) Cavitation model, the vaporization pressure is 3367.8Pa.

Each parameter can be set after the completion of the model for iterative calculation.

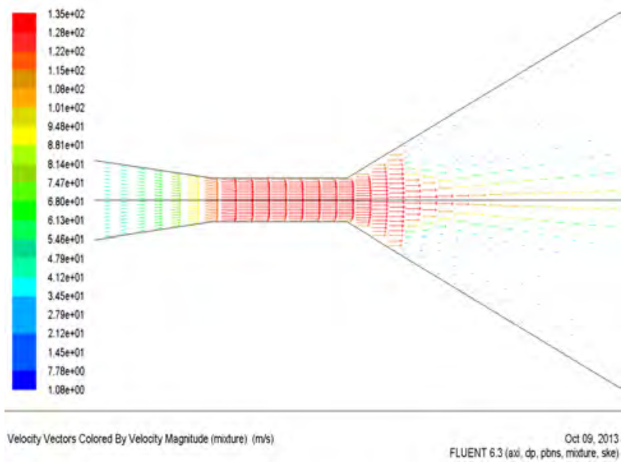

Figure 3. Velocity vector

IV. THE RESULTS OF SIMULATION AND ANALYSIS

A. Basic description about the nozzle internal cavitation phenomenon

Fig .3 and Fig .4 is the flow field inside the nozzle of the local velocity vector diagram and phase volume concentration distribution nephogram, when nozzle divergence Angle is of 50 °. From Fig .3 it can be seen: the fluid nozzle vortex occurs at the cylindrical section of the nozzle near the exit, thereby forming a low pressure area. From Fig .4 it can be seen: it is a vortex zone that the gas phase is significantly higher than other regions, and the maximum content of gas occurs in the near wall region, which shows that the partial pressure of the inside of the nozzle has dropped to below the saturated vapor pressure of water, leads to the formation of a large number of cavitation bubbles.

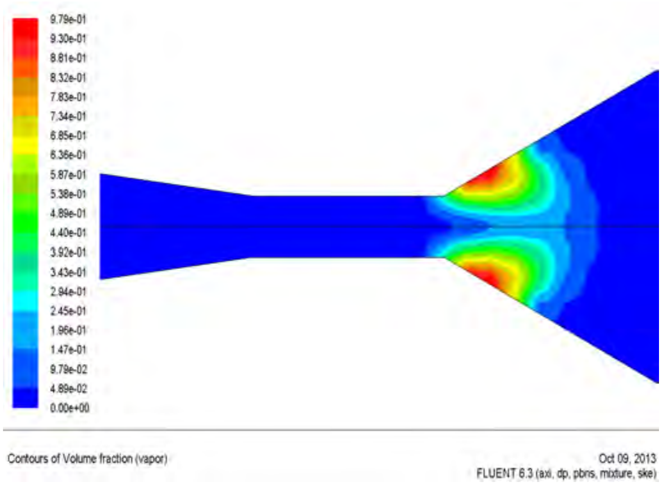

Figure 4. Nozzle internal gas phase contours

The expansion of the nozzle segment were taken angle 50 °, 60 °, 70 °, 80 °. when the other taken a fixed value of the constant size parameters, the nozzle wall is gas volume content of the curve shown in Fig .5.

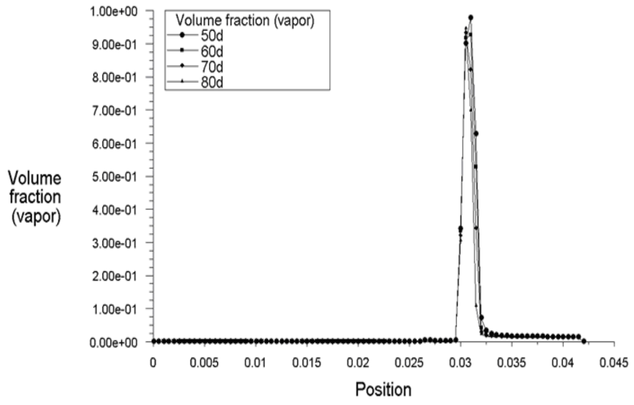

Figure 5. The content of the gas phase under different Angle of expansion graph

In Fig .5, when the nozzle expansion section take a different angle, the volume of the gas phase have the same change trend that its content are gradually increase to the maximum content before they are reduced to zero. When the nozzle expansion angle of 50 ° is taken, the rate of vaporization of water in nozzle is highest, and with the increase of expansion Angle, the rate presents the biggest first then decreases after rising trend. The biggest vaporization rate point is furthest distance from the nozzle cylindrical section, and with the increase of divergence Angle, the maximum point of vaporization rate continuously reduce the distance with the nozzle of the cylindrical section at that angle.

V. CONCLUSIONS

This article is based on the advanced computational fluid dynamics software Fluent， we have completed the analyses of the convergent-divergent nozzle's internal flow field under different expansion Angle,came to the following conclusions:

1. Convergent-divergent nozzle in the export area of cylindrical section will form local low-pressure area, the partial pressure of the region have fallen below the saturated vapor pressure of water, and can lead to a large number of cavitation bubbles to form.

2. Under different expansion angles, Nozzle internal fluid content of gas phase's change trends are basically identical, after first increases to maximum content then reduce to 0.

3. With the increase of nozzle divergence Angle, the distance between maximum vaporization rates appeared point with nozzle cylindrical section have decreased.

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