

Study on Pressure and Velocity Characteristics of Double Chamber Self-excited Oscillating Nozzle under Different Second Chamber Length

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Abstract: Self-excited oscillating pulse nozzles are widely used in cleaning, mining and fire protection because of their high efficiency and low cost. In this work, the CFD numerical simulation technology and the acceleration factor γ assistant evaluation method are used to study the pressure and velocity characteristics of double chamber self-excited oscillating nozzle under different second chamber length. And the pressure and velocity characteristics of the self-excited oscillating nozzles are compared and analyzed to find out the critical factors that affect the pulsed jet. The results show that increase of the length of the second chamber can effectively increase the acceleration effect of the jet speed, and thus enhancing the effect of the jet pulsation.

1. Introduction

The high-pressure water jet is widely used by many industries, such as cutting, fire engineering, drilling, and cleaning are just a few [1-4], with the increasing pressure on working conditions, piping and high-pressure water pumps and other equipment requirements are increasingly harsh, resulting in a sharp increase in production costs [5, 6]. The self-excited oscillation nozzle due to its self-oscillation, which produces pulsed jet characteristic, has the potential to achieve high operating efficiency under low operating conditions [7-9]. The academic and market value to carry out research work on self-excited oscillating nozzles is invaluable.

The proportion of the structural parameters of the self-excited oscillating nozzle is the primary factor affecting the efficiency of the pulsed jet, and the reasonable ratio of the structural parameters will produce the pulsed jet with a stable frequency and high speed [10]. The effect of the pulsed jet is mainly influenced by the length of the chamber, if the cavity length is too short, the static pressure feedback of the outlet section caused by the low pressure vortex ring in the chamber is smaller, which resulting in reduced pulse jet effect. In this study, FLUENT is used to numerically simulate the internal flow field of the dual chamber self oscillation nozzles, and to research the pressure and velocity characteristics of the nozzles with different second chamber lengths.

2. Model Establishing and Calculating

2.1 Geometric Model and Boundary Condition

The geometric model used in numerical simulation is shown in Fig.1, and the simulation experiment is divided into 6 kinds of working conditions with different chamber lengths. Inlet boundary conditions use pressure inlet, the inlet pressure is set to 1MPa. Outlet boundary conditions use pressure outlet, outlet pressure is set to atmospheric pressure; and no-slip boundary condition is used for the wall. The pressure implicit solver is used in the numerical simulation, using realizable $k-\varepsilon$ turbulence model and SIMPLE algorithm, the discrete formats of momentum and pressure are

QUICK and PRESTO! the discrete scheme of turbulent kinetic energy and dissipation rate is second order upwind [11].

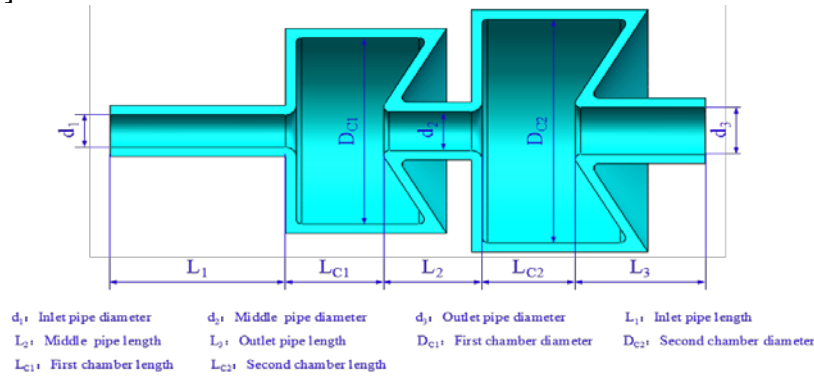


Fig. 1 The schematic diagram of double chamber self-excited oscillating nozzle structure

2.2 Mathematical Model

The turbulent model uses the realizable k- ε model, the transport equation is [12]:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial t} = \frac{\partial}{\partial t} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - \rho \varepsilon - Y_M \quad (1)$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho \varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + \rho C_1 E \varepsilon - \rho C_2 \frac{\varepsilon^2}{k + \sqrt{\nu \varepsilon}} + C_{1\varepsilon} \frac{\varepsilon}{k} C_{3\varepsilon} G_b + S_\varepsilon \quad (2)$$

Where G_K : the generation of turbulence kinetic energy due to the mean velocity gradients; G_b : the generation of turbulence kinetic energy due to buoyancy; Y_M : the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate; Empirical constant: $C_{1\varepsilon}=1.44$, $C_{2\varepsilon}=1.92$, $C_{3\varepsilon}=0.09$, $C_2=1.9$;

The injection distance of pulsed jet is determined by the velocity of the core jet region. To better evaluate the acceleration effect of the self-excited oscillation nozzle, a dimensionless constant acceleration factor γ is introduced to assist the evaluation.

Acceleration factor γ :

$$\gamma = \left(\frac{V_2'}{V_1'} \right) / \left(\frac{d_1}{d_2} \right)^2 - a = \frac{V_2' d_2^2}{V_1' d_1^2} - a \quad (3)$$

Where V_1' : Average velocity at the end of inlet pipe; V_2' : Average velocity at the beginning of inlet pipe; d_1 : Inlet pipe diameter; d_2 : Outlet pipe diameter; The first chamber of the nozzle, $a=1$; The second chamber of the nozzle, $a=2$;

This parameter reflects the acceleration effect of the self-excited oscillation nozzle outlet section. When $\gamma < 0$, the velocity of the outlet section is less than the theoretical value, so there must be energy loss. When $\gamma > 0$, indicating that although there may be energy loss in the self-oscillating nozzle, the export velocity above the theoretical value can still be achieved by its own structure. If $\gamma > 0$, it shows that this structure has the potential to achieve high operating condition requirements under low working conditions.

3. Flow Field Simulation Results Analysis

Observing the axis pressure and velocity curve, we can see that without changing the rest of the structural parameters, increasing the length of the second chamber L_{C2} can effectively improve the acceleration effect of the pulsed jet. Self-excited oscillating nozzles can produce effective pulsed jet under these 6 cases, the second chamber twice the amplification effect is obvious. Moreover, the longer the second chamber length L_{C2} , the more obvious the pulse jet effect is. The change trend of velocity and pressure in the first chamber of the self excited oscillation nozzle is consistent, have

better pulse effect. The effect of the first time speed growth in the second chamber is similar, but as the length of the chamber increases, the position of the second time speed increase is also displaced accordingly. As the length of the second chamber increases, the jet blocking effect is enhanced and the jet peak is effectively increased.

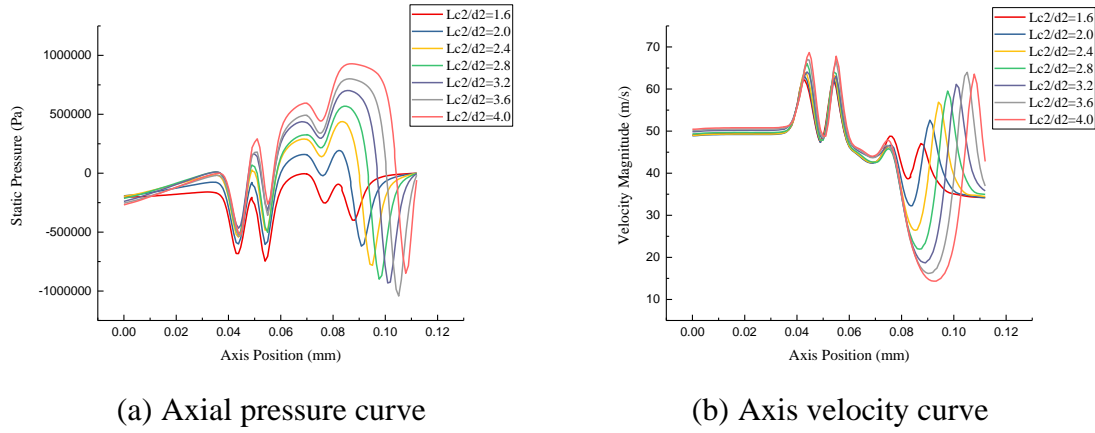


Fig. 2 The curve of axial pressure and velocity under different second chambers length

Table 1. The dual-chamber self-excited oscillation nozzle operating parameters table with different Second chamber length L_{C2}

L_{c2} / d_2		1.6	2.0	2.4	2.8	3.2	3.6	4.0
L_{c2} [mm]		13.44	16.80	20.16	23.52	26.88	30.24	33.60
ΔP [Pa]	I	-581508	-527584	-466518	-465864	-329480	-338269	-257190
	II	-391274	-778399	-486174	-1225192	-1360675	-1535078	-1444607
ΔV [m/s]	I	12.49	13.09	13.73	14.19	12.66	15.99	16.81
	II	4.39	10.22	14.13	16.91	17.18	20.21	19.32
γ_P	I	80.29%	82.18%	83.96%	85.06%	80.24%	89.51%	91.59%
	II	58.93%	78.82%	91.73%	101.25%	100.40%	110.62%	124.48%
γ_W		-3.86%	20.26%	37.27%	47.31%	51.25%	61.62%	58.38%

Where I : The first chamber; II :The second chamber ; γ_P : The acceleration factor of part; γ_T : The acceleration factor of whole;

Observation Table 1 shows that with the continuous increase of the second chamber length L_{C2} , the value of ΔP becomes smaller and the ΔV increases continuously, which shows that the acceleration effect of self-excited oscillating nozzle is enhanced and the pulse jet effect is improved. In the meantime, the γ values in the first chamber are similar, while the γ values in the second chamber have been greatly increased, and the acceleration factor γ of the double chamber as a whole has also been greatly increased. This shows that increasing the length of the second chamber can effectively improve the jet acceleration effect, so as to improve the kinetic energy and striking power of pulse jet. In view of Fig. 2, the pulsed jet initially formed has a higher flow velocity through increasing velocity and jet blocking in the first chamber, if the second chamber length is too small, it can not form an effective block, so that the energy storage effect is poor, resulting in the second speed amplification effect ineffective. After increasing the length of the chamber, the effect of the energy storage stage in the second chamber can be enhanced, so that the pulse jet at the outlet pipe has a better acceleration effect. The results of pulsating matching is evaluated by the growth factor gamma, It can be seen that the reasonable parameter range of second chamber length L_{C2} is $3.2 \leq L_{C2}/d_2 \leq 4.0$, in this range, the self-excited oscillation nozzle will produce a better jet acceleration effect and the more obvious pulse jet. Within a reasonable range of parameters, the acceleration factor of part increases with the increase of L_{C2} , but the pulsation matching is the

highest when $L_{C2}/d_2=3.6$, so $L_{C2}/d_2=3.6$ is the best second cavity length ratio.

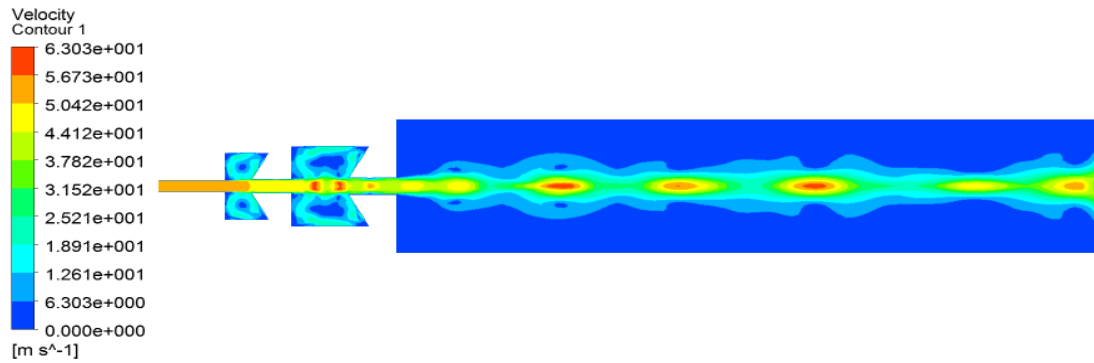


Fig. 3 Numerical simulation results of external flow field

It can be seen from Fig. 3 that when $L_{C2}/d_2=3.6$, the obvious periodic velocity pulsation appears in the external field jet, which shows that the structure parameter of self-excited oscillating nozzle is reasonable and the better pulse jet effect can be obtained theoretically.

4. Conclusions

1) The structure parameter matching of the self-excited oscillating nozzle has a significant impact on the production of the pulsed jet, and the chamber length affects the pulse jet generation effect. A reasonable range of the second chamber length of the self-oscillating dual-chamber nozzle is: $3.2 \leq L_{C2}/d_2 \leq 4.0$. When $L_{C2}/d_2 = 3.6$, the pulse jet outlet speed can be increased by nearly 61.62%.

2) The double chamber self-excited oscillation nozzle can effectively produce the pulsed jet, and the operating parameters are better than the single chamber structure. If the structure design is reasonable, the effect of $1+1>2$ can be achieved.

3) When the operation parameters of dual chamber self-excited oscillating nozzle match with the structural parameters, a stable pulsed jet can be generated. Increasing inlet pressure can effectively improve the effect of the pulse jet produced by the nozzle, however, the pulse jet frequency generated when the inlet pressure is 1MPa is the most stable.

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