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Improvement of Diaphragm Discharge Jet Water Treatment Device

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Abstract

An air supplementing type plasma synthetic jet (ASPSJ) generator has been developed in this paper. A one-way check valve, increasing the air refill supply at the recover stage, is connected to a typical spark discharge plasma synthetic jet(PSJ) generator. The ASPSJ improves jet flow continuity of typical PSJ and can get higher energy synthetic jet. The effect of different valves on the maximum average jet flow speed is researched with different electric parameters. The best electric parameters for the highest synthetic jet flow speed are obtained by orthogonal test. For the test ASPSJ generators,the best loading voltage frequency, amplitude, and duty cycle are 150 Hz, 50 kV and 15%.The results show that ASPSJ strengthens the maximum average jet flow speed by above 20%.The best actuation frequency is increased, and the actuation frequency bandwidth for maximum jet flow speed enlarges from one point to 100 Hz. Better airflow control effect can be expected by ASPSJ in wind tunnel tests. The research results provide guidance for further active flow control application.

Keywords

Diaphragm discharge, Sewage treatment, Energy conservation.

1. Introduction

Spark discharge-based plasma jet technology is one of the research hotspots of active plasma flow control technology.It was first proposed by the Johns Hopkins University Applied Physics Laboratory in 2003.

This type of spark discharge plasma synthetic jet generator, due to the local maximum instantaneous velocity of the jet generated by it is up to hundreds of meters per second, it has a good active control effect on high-speed incoming flow, especially supersonic incoming flow, and has gradually become a scholar at home and abroad. Concerned.

For more than a decade, Johns Hopkins University, Florida A & M University, Florida State University, Texas State University, Rutgers State University of New Jersey, NASA, University of Illinois, Toulouse, France The University and Aerospace Research Center (ONERA), South Korea's Ulsan University, Nanjing University of Aeronautics and Astronautics, Air Force Engineering University, National University of Defense Technology, and other units have successively carried out theoretical analysis of spark discharge plasma synthetic jets, particle image velocimetry (PIV) or schlieren Experimental and numerical simulation research. Scholars from abroad and the National University of Defense Technology have applied spark discharge plasma synthetic jets to conduct flow control experiments under supersonic flow.

The spark discharge plasma synthetic jet generator adopts the form of spark discharge in the cavity. In the working cycle, only the jet outlet is used for suction recovery, and the amount of backfill gas

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is limited. As the generator working time increases, the time required for the recovery phase of the suction is drawn. Insufficient air intake, significantly reduced jet velocity, limited generator operating frequency, and difficult to increase jet energy.

This paper proposes a gas-filled spark discharge plasma jet generator to solve the above problems. The structure and working principle of the gas-charged spark discharge plasma jet generator are described in detail. The jet characteristics of different types of check valve pair generators are studied under different loading electrical parameters. And use orthogonal experiments to find the optimal working electrical parameters of the supplemental gas generator to obtain the highest synthetic jet velocity.

2. Experimental device

The structure and working principle of a conventional spark discharge plasma jet generator is shown in Figure 1. It consists of an insulating cavity with an exit hole and a pair of electrodes. There are three stages to form a jet, namely, in the Spark discharge is performed in the cavity to generate plasma (see Figure 1 (a)); the high temperature accompanying the discharge heats the gas in the cavity, causing its temperature and pressure to rise rapidly, so that it is quickly ejected from the outlet to form a flow field control Gas jet (see Figure 1 (b)); the instantaneous completion of the jet causes the cavity to generate negative pressure and temperature drop, and then the external gas multiplies the cavity to fill the cavity in preparation for the next discharge and jet formation (see Figure 1 (c)). The phases constitute a jet cycle.

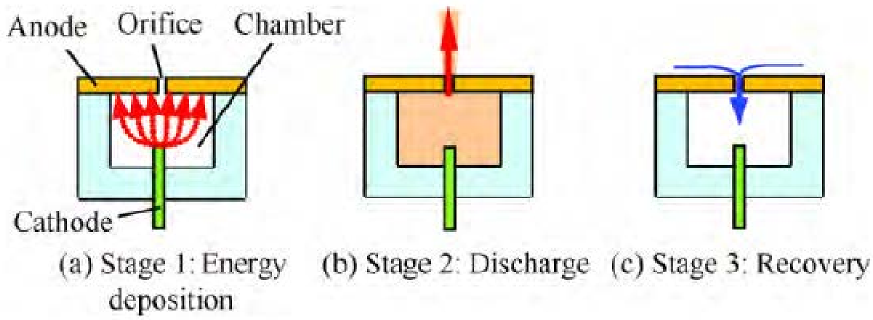

Fig. 1 Stages of spark discharge plasma jet operating cycle.

It can be seen from Figure 1 that at present, this type of jet generator only relies on the jet outlet for suction recovery in the working cycle, and the amount of backfill gas is limited. The cavity heats up after work, and the natural cooling time is more direct, which directly affects the speed of suction recovery. Time, the generator's working frequency is limited. As the generator's working time increases, the time required for the inhalation recovery phase is drawn, the inspiratory capacity is insufficient, the jet velocity is significantly reduced, the produced jet energy is difficult to improve, and the flow control ability Weaken.

The gas-filled spark discharge plasma jet generator is shown in Figure 2. It consists of a cylindrical cavity, a gas-filled check valve, a female electrode, a positive electrode, and a high-voltage pulse power supply. The cavity has 4 openings, one of which is open As a jet outlet; an opening is connected to the supplemental gas check valve; the two ends of the opening are respectively inserted into the anode electrode and the cathode electrode (to be sealed), and are electrically connected to the two output ends of the high-voltage pulse power supply.

The cavity is made of insulating material, and the generator cavity material involved in the experiments in this article uses glass; the cavity wall thickness is 1mm, the inner diameter is 8mm, and the degree of liveness is 38mm. The diameter of the jet exit is 1mm. In order to facilitate the electrode sealing and fixing, the cavity The diameter of the two ends of the body is reduced, and the diameter of the opening at both ends is 3 mm. The cathode and anode electrodes use multi-core high temperature resistant wires, and the electrode spacing in the cavity is 15 mm.

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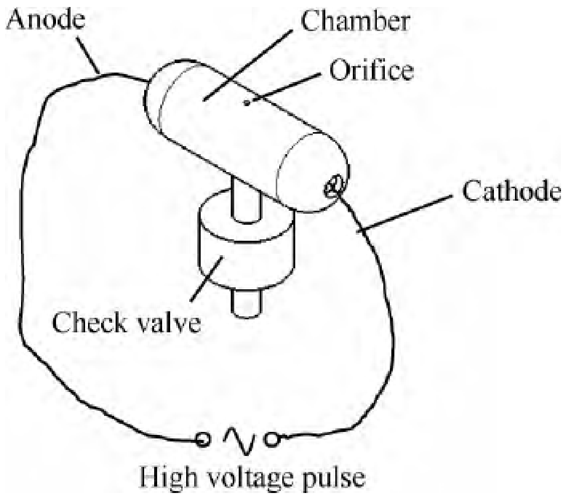

Fig. 2 Air supplementing type plasma jet generator

The gas-supplying spark discharge plasma jet generator is connected with a gas-supply check valve on the opposite wall of the discharge exit of the discharge chamber, as shown in Figure 3. When the chamber discharges, a large amount of heat is generated by the plasma, which makes the gas instantaneous. The jet is expanded and pressurized to form a jet, and then during the process of suction recovery, the check valve automatically opens and closes under the pressure difference between the internal and external pressure of the cavity. When the cavity shows a negative pressure state, the check valve automatically opens the suction to supplement the cavity The gas restores the pressure. When the chamber is under high pressure, the check valve closes automatically to prevent leakage.

In order to restore the air pressure in the cavity after discharge as soon as possible, the area of the channel between the check valve and the container is set to several times the nozzle outlet to shorten the gas supplement process and increase the generator's operating frequency. After the jet generator has been working for a period of time, The temperature of the cavity will also increase, and it is difficult to recover only by the suction of the jet nozzle, which will cause the speed of the jet to decrease. Using a one-way valve, the air supply channel is larger, and the suction recovery process is less affected by the temperature rise of the cavity. The gas check valve can make the jet generator quickly replenish gas during the discharge gap, so that the cavity air pressure is restored as soon as possible, and the next cycle of discharge and jet is performed.

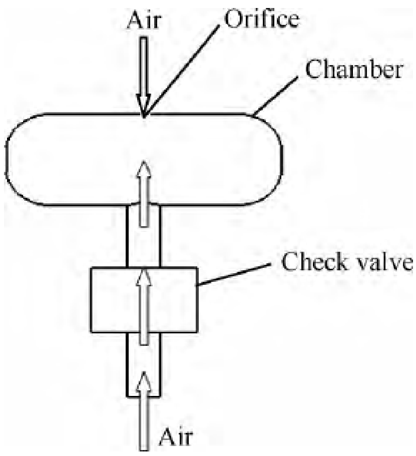

Fig. 3 Air suction recovery stage

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Obviously, the gas supplement check valve can accelerate the gas supplement rate and increase the amount of gas replenishment in the cavity, which can maintain the jet velocity, reduce the gas supplement recovery time, and shorten the discharge cycle, making the jet more continuous and stable.

Figure 4 is a plasma jet experimental system, which mainly includes a gas-filled plasma jet generator, a high-voltage pulse power supply, an ac / ac voltage regulator, a pitot tube speedometer, and an oscilloscope.

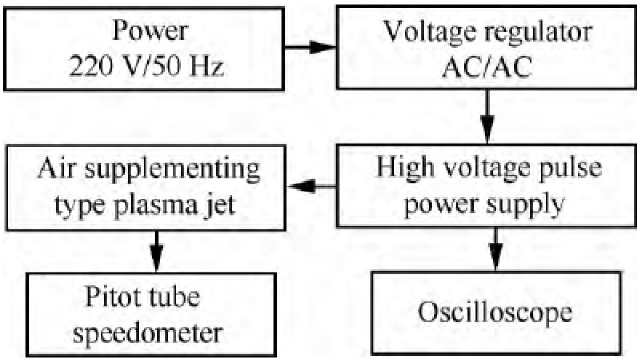

Fig. 4 Plasma jet experiment setup overview

The amplitude of the high-voltage pulse signal is adjusted by the ac / ac voltage regulator. The oscilloscope (model Tektronix dpo2012) is used to measure the driving signal frequency. The electrical parameters loaded in the experiment are as follows: High-voltage pulse signal amplitudeU0 ~ 50 kV, frequency 20 Hz ~ 5 kHz, duty cycleτ5% ~ 50%.

Considering that the effect of the jet on the flow control is mainly the result of the overall energy (such as momentum and flow) of the jet, the local maximum instantaneous velocity cannot characterize the overall strength of the jet and its role in flow control. Therefore, this article uses a U-shaped pipe fluid The cylindrical difference type pitot tube speed meter measures the average velocity of the obtained plasma jet. The liquid column difference U-tube can also avoid electromagnetic interference. The measured velocity can directly estimate the average energy level of the jet. And the U-tube measurement Convenient and visual. Pitot tube nozzle diameter is 0.7mm. When measuring, the nozzle is directly opposite to the jet flow, so that the two axes coincide. The air velocity measured by the Pitot tube is the average flow velocity of the jet entering the measuring tube. In the experiment, the distance of the Pitot tube measurement probe The end face of the jet exit of the generator is 1 mm, and the data is read after the water column difference of the U-tube pressure gauge is stabilized.

In theory, the time-averaged dynamic pressure of the jet is determined by equation (1).

$$\rho_1 g h_1 = \int_0^1 0.5 \rho_{jet}(t) v_{jet}^2(t)\,dt \tag{1}$$

Where ρ_{jet} Gas density for jet, kg / m³; v_{jet} Instantaneous velocity of jet, m / s; ρ_1 Is the density of the liquid in the manometer, kg / m³; h_1 It is the water column difference of the manometer in the experiment, m; g is the acceleration of gravity, which is taken as 9.8 N / kg. However, the velocity of the plasma synthetic jet changes rapidly, and the density changes with time and space position, it is difficult to be accurate Measurement and calculation.

As an approximate calculation, assuming that the gas density in the cavity remains unchanged, ρ_a The atmospheric density is taken as 1.225 kg / m³. In the experiment, water was used as the liquid in the U-shaped pipe, so it was taken as 1 000 kg / m³; from the pressure measuring principle of the U-shaped pipe and Bernoulli's equation, the average speed of the jet exit can be obtained The square root value is approximately

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$$v_a = \sqrt{\frac{2\rho_1 g h_1}{\rho_a}} \tag{2}$$

The measurement accuracy was verified through experiments, indicating that the measured speed v_a When it is above 20 m / s, its measurement accuracy is within 4%.

3. Experimental results and analysis

3.1 Performance optimization of one-way valve to jet generator

In order to verify the performance of the gas-supplying plasma jet generator, experiments were first performed on different types of gas-supplying check valves.

This experiment mainly uses medical plastic diaphragm check valves, whose main materials are PP, PA, PVDF and other materials, and the diaphragm material is silicone. In the experiment, two straight-through check valves were selected, and the models were ZCKL-DCV06 and ZCHJ. -22 (see Figure 5), the nominal diameters are 2mm and 6mm, respectively.

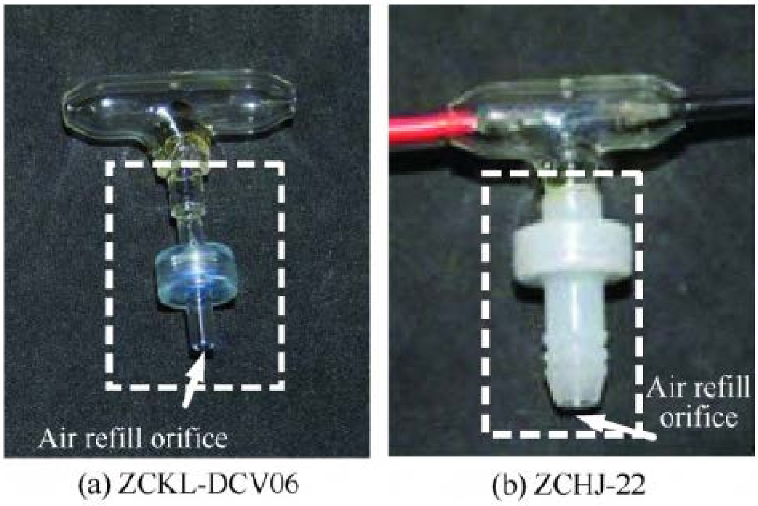

Fig. 5 Check valves

In the experiment, the air inlet of the check valve is closed first, and the voltage amplitude is adjusted to measure the maximum value of the jet velocity of the generator under a certain high-pressure pulse signal frequency and duty cycle. v_{max}; Then open the check valve air inlet, and under the same electrical parameters, measure the maximum jet velocity of the generator when the check valve is working.

Figure 6 shows the ZCKL-DCV06 one-way valve with a nominal diameter of 2mm under different duty cycles. v_{max} The curve that changes with frequency. As the frequency increases, they all show a trend of increasing first and then decreasing.

In Figure 6 (a), τ When = 5%, f <200Hz, when the check valve is opened, v_{max} Both increase, f = 150Hz, an increase of 16.2%; and f When it is> 200Hz, it is reduced, and the generator works in a saturated state. τ At 10%, in each frequency range, the opening of the check valve can play a role in optimizing the performance of the generator. v_{max} Significantly increased, the maximum value increased above 40 m / s, at f At 150 Hz, the optimization effect of the check valve on the generator is significant, an increase of 15.1% (see Figure 6 (b)), in τ= 15% (see Figure 6 (c)), when f f> 100 Hz, the opening of the check valve makes it stable at about 43 m / s in the range of 100-200 Hz f At 200Hz, v_{max} Increased 22.6%. It shows that the check valve can make the generator jet velocity more stable and continuous, and the working frequency band of high jet velocity is expanded from a single point to 100 Hz. At this time, in Figure 6 (c), v_{max} A platform emerged, that is, after using a check

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valve to supplement the air, the generator can maintain high-speed jets in the 100 Hz frequency band between 100 and 200 Hz.

In the case of maintaining a high jet velocity, increasing the operating frequency, that is, the number of jets flowing out, means that the intensity of the synthetic jet per unit time is enhanced. Under the condition that the energy of each jet is the same, the high operating frequency makes the average velocity of the jet increase. If applied to flow control, it is obviously expected to obtain better results.

As a whole, when the excitation frequency f When it is lower, the inspiratory recovery time is shorter in a single excitation cycle of the exciter, and the air pressure from the jet outlet makes the air pressure in the cavity fully restored, and the role of the zckl-dcv06 check valve is weak. The recovery time of inhalation is gradually shortened during work, and the replenishment of air from the jet outlet is not enough to quickly restore the air pressure in the cavity. At this time, the opening of the check valve can increase the inspiratory volume, increase the recovery speed, and enhance the energy of the jet.

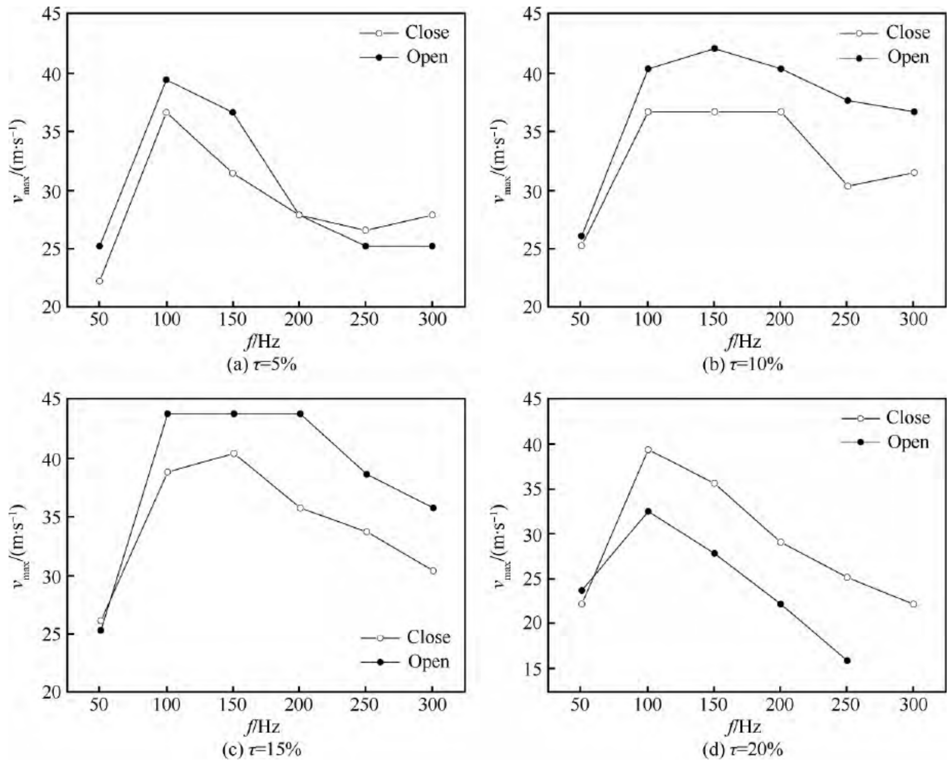

Fig. 6 v_{max} with 7CKIL-DCV06 check valve air refill orifice close and open

Duty cycleτIs the ratio of the energization time of the high-voltage pulse signal to the excitation period,τHigher means the longer the discharge time in a single excitation cycle, the greater the energy released during the discharge process.

The check valve is closed by the action of mechanical parts (diaphragms), and there is a hysteresis during the flow of air through the valve. Therefore, the effect of gas supplement is related to its response characteristics. The response characteristics of check valves vary with different models. different.

The above experiments show that the duty cycleτThe discharge time is relatively short in a single excitation cycle, and there is sufficient time for the suction to recover from the jet outlet, and the role of the check valve is not obvious; when the duty cycle is moderate, the discharge gap time is suitable for the closing response speed of the check valve. The effect of qi is better; while the duty cycle is too large (for exampleτ= 2000), the discharge time in one cycle is longer, the response speed of the check valve closing cannot keep up with the rhythm of discharge, and air leakage occurs. The result is a negative effect. Instead of increasing the jet velocity, it has decreased.v_{max}.

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This shows that for the gas-filled plasma jet generator, there is an optimal value between the discharge duty cycle and the jet operating frequency, and research is needed.

Figure 7 shows the maximum value of the jet velocity of the ZCHJ-22 check valve with a nominal diameter of 6mm to the generator in the closed and open state.v_{max}From Figure 7 (a) and Figure 7 (b), it can be seen that when the duty cycle is 5% and 10%, when the check valve works at most frequencies, the jet velocity of the jet generator can be increased.v_{max}But the increase is small, f = 50 Hzτ= 5%v_{max}Increased from 18.8m / s to 21.2m / s, an increase of 12.8%, andτAt 10%, it is increased by 1500. Compared with the zckl-dcv06 check valve, the performance optimization is slightly weaker. At low frequencies, the role of zchj-22 is more obvious. It may be that after the nominal diameter increases, the check valve The response speed is reduced, and under high-frequency excitation, the hysteresis is serious, and the gas supplement effect is reduced.

WhenτAt = 15% (see Figure 7 (c)), at each frequency of the experiment, the maximum speed of the jet can be greatly increased after the check valve is opened.v_{max}The increase rate is 19.5% ~ 27.5%. f At 100 Hz,v_{max}From 32.5 m / s to 39.4 m / s, an increase of 21.2%. f > 200Hz, the optimization of the check valve is still relatively obvious. f = 300 Hzv_{max}The largest increase is 27.5%. Compared with the zckl-dcv06 check valve, the performance optimization is better.

But whenτAt 20% (see Figure 7 (d)), at each frequency, after the check valve is opened, the maximum jet velocity-, And both decrease. When the duty cycle is large, the one-way valves selected in the article have a negative effect.

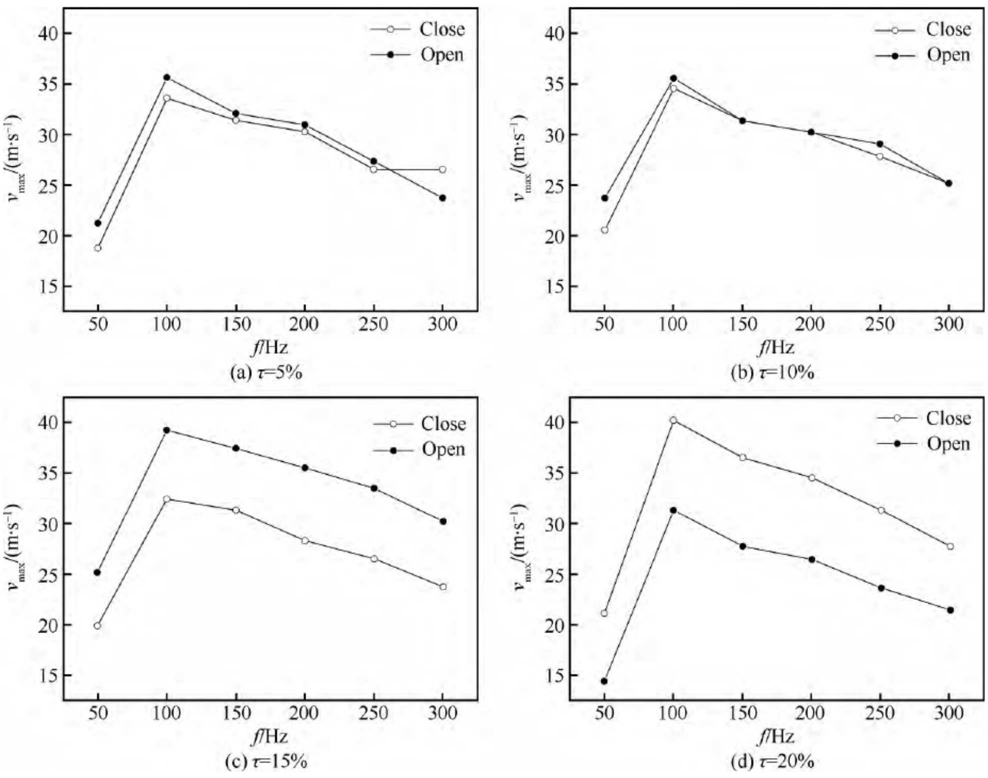

Fig. 7 v_{max} with ZCHJ-22 check valve air refill orifice close and open

In general, the changing trend of Figure 7 is similar to that of Figure 6, both of which increase first and then decrease with increasing frequency.τWhen = 15%, thev_{max}The lifting effect is relatively obvious.τAt 5% and 10%, the check valve can optimize the performance of the jet generator at certain frequency points. Similar to the zckl-dcv06 check valve,τIn the case of = 20%, the zchj-22 check valve cannot play a role in increasing the jet velocity of the generator. This shows that the check valve is not suitable for the situation where the duty cycle is too large.

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The experimental results show that the check valve with a nominal diameter of 2 mm improves the jet performance better than the check valve with a nominal diameter of 6 mm.The reason may be that the response speed of the check valves with different nominal diameters is different. The small response speed is fast, and the work performance is better under high frequency excitation.

The above experimental research shows that the addition of a one-way valve can improve the stability and continuity of the jet, significantly increase the jet velocity of the plasma jet generator under a given loading electric parameter condition, and expand its operating band of high jet velocity.

3.2 Effect of loading electrical parameters on the performance of a gas-filled plasma jet generator

From Section 2.1, it can be seen that the loading electrical parameters have a greater impact on the gas-filled plasma jet generator, and the check valve does not play a role in optimizing the generator performance in all experimental electrical parameters. Therefore, it is necessary Optimized design of the supplemental spark discharge plasma generator to provide guidance for its application in flow control.

Due to the many influencing factors of the plasma jet generator, it is difficult to analyze the major and minor effects of the main influencing factors.The orthogonal experiment method is feasible and applicable to the optimization experiment of the plasma jet generator.

The orthogonal experiment method is a scientific method that uses a standardized "orthogonal table" to reasonably arrange multi-factor experiments based on the principles of mathematical statistics, selecting an appropriate number of representative experimental points from a large number of experimental points The advantage of this method is that it can find out the influence of each factor on the experimental index through a small number of highly representative experiments. Optimal parameter combination.

In the study, orthogonal experiments were performed on the working electrical parameters of the plasma jet generator with the two selected one-way valves in order to give the optimal parameter combination.

In the experiment, the plasma jet velocity v was selected as an index to measure the performance of the gas-filled plasma jet generator, and the frequency of the excitation high-voltage pulse signal was selected. f Voltage amplitude U And duty cycle τ As a factor of investigation, the experiment was arranged using an orthogonal table of the form. The level of controllable factors developed is shown in Table 1.

Table 1 Orthogonal experiment factor level table

Level	A	B	C
	f/Hz	U/kV	τ/%
1	100	25	5
2	150	37.5	10
3	200	50	15

For different generators, with different check valves, there may be different optimal loading electrical parameters. The above results show that before using the supplemental spark discharge plasma jet generator for flow control, orthogonality can be performed first. In the experiment, for the determined spark discharge plasma jet generator and optional supplemental check valve, find the best loading electrical parameters, such as the amplitude, frequency and duty cycle of the loading voltage, to obtain a higher jet velocity. To improve the effectiveness of flow control.

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4. Conclusion

1) The proposed gas-supplying plasma jet generator improves the gas-supply amount of the generator's intake air and the stability and continuity of the jet, and can obtain a synthetic jet with higher energy.

2) One-way valve with compact structure and simple installation can be selected to realize the supplement of gas to the spark plasma jet generator without additional power.

3) For the supplemental spark plasma jet generator, there are optimal working electrical parameters. The spark plasma jet generator and the two types of check valves provided in the article have better performance than the check valve when working. Superior when working, the maximum speed of the jet can be increased by more than 20%, and the best loading electrical parameters are f =150 Hz, U=50 kV, τ=15%.

4) The optimization effect of the check valve with a nominal diameter of 2 mm is better than that of a 6 mm check valve, indicating that for the determined spark plasma jet generator, there is an optimal check valve nominal diameter.

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