Analysis of Poiseuille Flow Property in Two-Dimensional Micro Channels of Microfluidic Pneumatic Micro-Valve

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Abstract: In this paper, the control mechanism and mathematical description of the microfluidic flow in the microfluidic process of the PDMS membrane type pneumatic micro-valve were studied. The velocity and pressure variation law of the velocity field inside micro valve was analyzed by numerical simulation method. The influence of the two kinds of inlet drive modes on the working effect and the pressure flow characteristics of the pneumatic micro-valve was studied. The structure of the elastic solid valve diaphragm under the dual action of the airway and the liquid channel was analyzed. Deformation and stress distribution. The results show that the gas flow in the gas flow channel under the diaphragm by the vacuum part of the role of the formation of a suction gas vortex, pressure-driven mode was easier under the diaphragm to produce a strong gas vortex, resulting in internal and external pressure to promote diaphragm cut-off liquid channel; In the pressure pneumatic mode, the stress at both ends of the diaphragm was smaller, the membrane was not easy to tear failure.

Keywords: Micro-valve; Micro-nano flow; Gas-liquid coupling; Burnett equation

1. Introduction

Microfluidics is a technique that mainly controls the fluid in the microscale space [1]. The basic characteristics of microfluidic chips and the biggest advantage is the flexible combination of a variety of cell technology in a small controllable platform, Micro-pipelines, micro-pumps, micro-valves, micro-reservoirs, microelectrodes, micro-detection devices, etc. are integrated on a specific material substrate through microfabrication techniques [2,3]. The flow in the microfluidic chip is mainly of various channel flows, and its flow characteristics are generally in the range of 0.1-1 mm, which belongs to the field of hydrodynamic study [4]. However, as an integrated system, the flow in a microfluidic chip consists of a fluid drive, transmission, detection and control unit. The aerodynamic micro-valve is a typical microfluidic control unit. Due to the different control objects and control functions, the aerodynamic micro-valve has a variety of internal flow media and complicated nature. Driven by micro-electromechanical systems and microfluidic chip technologies, microfluidics is studied around the practicality of continuous assumptions, the manipulation of fluid motion, and local nanoscale flow. In the early 1990s, Pfahler et al. [5] found that the coefficient of flow resistance did not match the theoretical predictions through the pressure flow test in micro-channels, which attracted people's concern about the applicability of fluid continuity equations at microscale [6]. Since 2000, attention has been focused on the design
of microfluidic chips. Since the transport of samples between the various units depends on the flow of liquids, how to achieve flow control at the micro-scale becomes the key to microfluidic chip technology. In 2004, Stone et al. [7] published an article in the Yearbook of Fluid Mechanics, pointing out that the design of microchip needs to consider the influence of various physical factors and it is necessary to carry out further research on microscale fluid dynamics. Darhuber et al. [8] analyzed the physical mechanism of normal and tangential stress-driven surface fluids for discrete or continuous micro-control of small-scale systems and pointed out the contact-related boundary phenomena (such as separation pressure, line tension and slip shift, etc.) still need to be theoretically considered. In recent years, with the development from the microfluidic system to nanoscale, the micro-nano flow theory and nanotechnology are gradually introduced. In 2008, Han's research group [9] reviewed the flow phenomena in nanofluids. In 2010, Chemical Society Review published a special issue titled "From Microfluidic Applications to Nano-fluidics" [10], providing an overview of the latest international developments in micro and nano flow control.

Many scholars have studied Poiseuille flow in the Wiener Passage in the past. Harley et al. [11] studied the characteristics of sub-sonic gas flow in the Wiener channel using experimental and analytical methods and found that velocity slip conditions must be introduced at the boundary Arkilic [12] used perturbation method to solve the N-S equation describing the gas flow in the micro-channels. It was found that the calculated results and the experimental values were only in good agreement when the Knudsen number was small. Beskok et al. [13] studied the Poiseuille flow characteristics using the N-S equation and the high-order slip boundary conditions, and also performed numerical simulations with the DSMC method. It was found that the two methods agree well with the Knudsen number. When Knudsen number, the calculation results of N-S equation gradually deviate from the results obtained by DSMC. Experiments show that when the characteristic size of the flow field is on the order of micrometers or submicrometers, the velocity and temperature jumps of the fluid on the solid wall, as well as the thermal peristalsis, the electrokinetic effect, the viscous heating, the anomalous diffusion and the chemical effects, The internal play a leading role, leading to abnormal micro-scale flow phenomenon [14,15].

In recent years, some scholars began to use the Burnett equation to simulate the gas flow in the micro-nanochannels. Agarwal et al. [16] studied the planar Poiseuille flow using the augmented Burnett equation and found that solving the Burnett equation relative to the N-S equation yields better agreement with the results obtained using the DSMC method. Fang [17] also uses the augmented Burnett equation to simulate the flow and heat transfer problems in microchannels and gives the results. However, one of the biggest obstacles to using the Burnett equation is the numerical stability problem [18, 19]. In the past, the Burnett equation was used to solve the Poiseuille flow in two-dimensional flat plate only when it was convergent [16]. However, more and more gas flows in the micro-nano-electromechanical systems are in the area of slip flow (ie, [19, 20]), so it is necessary to further explore finding suitable mathematical methods in a wider range. Road flow description.

In this paper, the typical micro-nano-scale pneumatic valve flow for the object, The flow characteristics and mechanical laws of two-dimensional Poiseuille inside the passage were analyzed. The flow characteristics of the rectangular cross-section gas passage and the controlled arcuate liquid passage inside the control passage were analyzed, and the double role of elastic solid valve diaphragm in airway and liquid passage Under the structural deformation and stress distribution. The control mechanism and mathematical description of different media channels in the microfluidic process and the overcurrent characteristics of aerodynamic micro-valve under the gas-liquid coupling and the related influencing factors are clarified.2. Materials and Methods

Materials and Methods should be described with sufficient details to allow others to replicate and build on published results. Please note that publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information.
New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

2. Working principle and control model
In this paper, two-channel thin-film gas-actuated micro-valve is taken as an example to study the flow and heat transfer rules in micron-sized gas channels, as well as the deformation and deformation of elastic solid valve membrane during airway expansion and micro-valve closure.

As shown in Figure 1, an active microfluidic aerodynamic micro-valve consisting of glass and polydimethylsiloxane (PDMS) was investigated. The micro-valve is a multi-layer structure with a gas control flow path, a liquid controlled flow path, and a middle flexible PDMS valve membrane. As shown in Fig. 1. (a), the gas control channel and the semi-arc (cross-section high) liquid flow channel with rectangular section () are separated by a PDMS membrane with a thickness of 1 mm and are co-bonded to a glass substrate. When the lower air flow channel leads to the pressure gas, the gas film is deformed under the internal pressure and the upper liquid channel is squeezed to shrink the liquid flow passage cross section (as shown in Fig 1. b). When the deformation amount reaches a certain level , Liquid channel is cut off, micro-valve to achieve closure.

3. Control equations

3.1. Control of airflow
For the gaseous media in slip flow at the micron scale, this paper uses the unconditionally stable augmented Burnett equation and the boundary conditions to describe the working mechanism mathematically. The two-dimensional augmented Burnett equation in Cartesian coordinates can be written as:

\[ \frac{\partial \rho}{\partial t} + \frac{\partial p u}{\partial x} + \frac{\partial p v}{\partial y} = 0 \]  
(1)

\[ \frac{\partial}{\partial t} \left( \frac{\partial p u}{\partial x} \right) + \frac{\partial}{\partial x} \left( \frac{\partial}{\partial x} \left( \frac{\partial p u}{\partial x} \right) \right) + \frac{\partial}{\partial y} \left( \frac{\partial}{\partial y} \left( \frac{\partial p u}{\partial x} \right) \right) = \frac{\partial}{\partial x} \left( \frac{\partial \sigma_{11}}{\partial x} \right) - \frac{\partial}{\partial y} \left( \frac{\partial \sigma_{12}}{\partial y} \right) \]  
(2)

\[ \frac{\partial}{\partial t} \left( \frac{\partial p v}{\partial y} \right) + \frac{\partial}{\partial x} \left( \frac{\partial}{\partial x} \left( \frac{\partial p v}{\partial y} \right) \right) + \frac{\partial}{\partial y} \left( \frac{\partial}{\partial y} \left( \frac{\partial p v}{\partial y} \right) \right) = \frac{\partial}{\partial x} \left( \frac{\partial \sigma_{21}}{\partial x} \right) - \frac{\partial}{\partial y} \left( \frac{\partial \sigma_{22}}{\partial y} \right) \]  
(3)
\[
\begin{align*}
\frac{\partial e_x}{\partial t} + \frac{\partial e_{xu}}{\partial x} + \frac{\partial e_{xv}}{\partial y} &= - \frac{\partial pu}{\partial x} - \frac{\partial pv}{\partial y} - \frac{\partial \sigma_{xu} + \sigma_{xv} + q_i}{\partial x} - \frac{\partial \sigma_{yu} + \sigma_{yv} + q_i}{\partial y} \\
\end{align*}
\tag{4}
\]

among them:

\[
\sigma_{ij} = \sigma_{ij}^{(0)} + \sigma_{ij}^{(1)} + \sigma_{ij}^{(2)} + \sigma_{ij}^{(a)}
\]

\[
q_i = q_i^{(0)} + q_i^{(1)} + q_i^{(2)} + q_i^{(a)}
\]

Due to the effect of levitation, there are tangential momentum fluxes of gas molecules in the isothermal wall motion, in which the approximate molecule comes from the near-wall region [20], and the other half reflects back from the wall. When the inlet temperature and the wall temperature are different, there is a tangential temperature gradient on the wall surface. The existence of such a temperature jump causes the gas temperature to be less than the wall temperature, especially near the entrance, and a larger tangential temperature gradient results in a greater thermal creep effect. As a result of hot creep, the body is forced to flow from the lower temperature side to the higher temperature side, exacerbating the speed slip at the boundary. Therefore, in this paper, for the gas flow in the micro-channel of the valve, the velocity slip boundary condition considering thermal creep effect of the boundary is adopted:

\[
u_s = \frac{1}{2} \left\{ (2 - \sigma_i) u_s + \sigma_i u_w \right\} + \frac{3}{4} \frac{\mu \partial T}{\rho T} \frac{\partial x}{\partial w}
\tag{5}
\]

Of which: \( u_s \) is the inlet gas tangential velocity; \( u_w \) is the wall tangential velocity; \( \sigma_i \) is the proportion of diffuse reflection gas molecules, the other part of the gas molecules mirror reflection law.

The corresponding wall temperature of gas changes can be expressed as:

\[
T_w = \frac{2 - \sigma_T}{Pr} \frac{2\gamma}{\gamma + 1} T_s + \sigma_T T_e
\tag{6}
\]

Where: \( \sigma_T \) is the temperature adaptation factor; \( Pr \) is Prandtl number; \( \gamma \) is the specific heat ratio; \( T_s \) is the temperature near the wall of a molecule free path; \( T_e \) is the wall temperature.

In order to increase the stability of the calculation, the relaxation method can be introduced respectively in the above speed slip boundary and Burnett term:

\[
u = u^{old} + R \left( u^{new} - u^{old} \right)
\tag{7}
\]

\[
B = B^{old} + R \left( B^{new} - B^{old} \right)
\tag{8}
\]

Where: \( B \) represents the Burnett term and super Burnett term in the equation, old represents the value of the previous iteration, and new represents the newly calculated value.

3.2. Elastic membrane

For the PDMS diaphragm that separates the airway from the liquid passage, the nonlinear solid equations of the elastomer are used to describe the forces acting on the structure during deformation. The deformation force of the film structure is impulse pressure, liquid pressure and viscous force, where the gas pressure is a constant related to time, and the resultant force of liquid pressure and viscous force can be expressed as

\[
F = \bar{\eta} \\left\{ -pI + \left[ \eta \left( \nabla V + \nabla V^T \right) \right] \right\}
\tag{9}
\]
Where: $\vec{n}$ is the normal vector of the boundary; $\vec{V} = (u, v)$ is the velocity vector of the two-dimensional flow, $u$, $v$ is the flow velocity in the $x$, $y$ direction; $p$ is the pressure of the liquid; $\eta$ is the viscosity coefficient; $I$ is the identity matrix.

In this paper, we mainly analyze the flow characteristics and energy conversion of the micro-scale Poiseuille flow in the gas control channel. The finite volume method is used to solve the system's Burnett equation. The second-order windward Roe flux difference splitting scheme is adopted for the non-sticky item. The second-order central difference scheme is used for the stress tensor and heat flux. The Gauss-Equations, momentum equations and energy equations, Finally, the control airway flow velocity and pressure distribution, controlled flow passage through the flow rate changes and shut-off pressure, as well as the diaphragm stress and deformation and other indicators of parameters, with the micro-valve structure parameters and driving changes in the law.

**Figure 2.** Schematic structural parameters

| Name                | Symbol | Value       |
|---------------------|--------|-------------|
| Airway length $L_1$| $L_1$  | 500 ~ 600   |
| Airway height $h_1$| $h_1$  | 50          |
| Diaphragm thickness| $h_3$  | 50          |
| Liquid height $h_2$| $h_2$  | 50          |
| Liquid channel width| $L_2$ | 500 ~ 1100  |

**Table 1.** Parameter Planning Table

| Name                | Symbol | Value       |
|---------------------|--------|-------------|
| Airway length $L_1$| $L_1$  | 500 ~ 600   |
| Airway height $h_1$| $h_1$  | 50          |
| Diaphragm thickness| $h_3$  | 50          |
| Liquid height $h_2$| $h_2$  | 50          |
| Liquid channel width| $L_2$ | 500 ~ 1100  |

4. **Analysis of influencing factors**

4.1. **Airway width $L_1$ of the impact**

When the length of the gas channel is 800μm, the influence of velocity and pressure on the flow characteristics of the aerodynamic micro-valve is studied.
Figure 3. velocity-driven airway flow field distribution

Figure 4. pressure-driven flow field distribution in the airway

Comparing Fig. 3 and Fig. 4, we can see that regardless of whether the control airway is driven by speed inlet or pressure inlet, the pressure distribution in the airway flow field can be changed to warp the valve diaphragm to gradually close the flow passage cross section of the liquid passage. Different driving methods of control effect is not the same. As shown in Figure 3: As the inlet velocity increases from 50% to 30 m/s from 20 m/s, the velocity of the flow field inside the airway decreases gradually, and the velocity in the region right below the diaphragm decreases to the minimum. Pressure reached the maximum, pushing the valve diaphragm upward warping increased from 10.4 to 28.6; As shown in Fig. 4, as the inlet pressure increases from 1000 Pa to 1500 Pa, the warp effect of the valve diaphragm becomes more pronounced with increasing inlet pressure, and the amount of upward warp of the diaphragm increases from 22.8 to 48.7. Compared with the speed-driven mode, the pressure-driven closure of the liquid channel is better; The gas pressure under the diaphragm forms an isostatic ring in the warp-age region, which increases the driving force of the diaphragm deformation. At this moment, most of
the kinetic energy and pressure of the gas can be transformed into the elastic potential energy of the warpage of the supporting valve diaphragm.

![Figure 5](image)

**Figure 5.** actuation of different airway length of the micro-valve closing characteristics

Further analysis of different driving modes on the pneumatic micro-valve cut-off characteristics, As shown in Fig. 5, when the gas passage length \( L_1 > 550 \mu m \), the pressure-driven effect is obviously better than the speed-driven effect, and the flow rate decreases slowly as the gas length increases. When \( L_1 < 1100 \mu m \), the micro-valve closing effect is not obvious under the speed-driven condition, and the flow rate is greater than 20μm. Under the pressure-driven condition, the closing effect of the micro-valve is obvious with the increase of the gas passage length. When the gas passage length \( L_1 > 600 \mu m \), the flow rate is less than 13μm, the closure effect is more obvious.

4.2. The influence of \( L_2 / h_2 \) ratio of liquid channel

Fixed controlled liquid channel height of 50μm, in order to ensure the micro-valve closure effect, so that the airway width \( L_1 = L_2 + 100 \mu m \). When \( L_2 / h_2 = (10 \sim 20) \), the influence of velocity and pressure on the flow characteristics of aerodynamic micro-valve were studied.

![Figure 6](image)

**Figure 6.** velocity-driven airway flow field distribution
It can be seen from Fig. 6 and Fig. 7 that regardless of whether the control air passage is driven at a speed inlet or a pressure inlet, the pressure distribution in the air flow field can be changed to warp the valve diaphragm to change the flow cross section of the liquid passage. As shown in Fig. 4: As the inlet pressure increases from 500 Pa to 500 Pa, the degree of bending of the valve diaphragm gradually increases with the increase of inlet pressure, and the degree of warpage of the diaphragm changes significantly with the increase of inlet pressure. The amount of upward warpage of the diaphragm increased from 23.7 to 43.3. This shows that: compared to speed-driven approach, the pressure-driven closure of the liquid channel better. At this time, the pressure in the gas channel under the diaphragm becomes obvious asymmetric distribution, and most of the kinetic energy of the gas is transformed into the elastic potential energy of the warpage of the diaphragm supporting the valve, and the valve diaphragm is upwardly closed to close the liquid passage upwardly.

**Figure 7.** pressure-driven airway flow field distribution

![Diagram showing pressure-driven airway flow field]
Further analysis of different driving modes under the aspect ratio of the valve effect of micro-valve as shown in Figure 8 shows: the pressure-driven effect is significantly better than the speed-driven effect. As the liquid channel aspect ratio increases, the flow rate decreases rapidly. When \( L_2 / h_2 > 18 \), the micro-valve closed more than 80% under the condition of speed driving, and the passage height of the liquid passage was less than 10μm. The micro-valve closing effect was excellent under the pressure driven condition and the flow passage height of the liquid passage was less than 1μm. The reason why 100% did not reach 100% at this moment was mainly caused by the use of two-dimensional model. The follow-up experimental research shows that when \( L_2 / h_2 > 18 \), the pressure-driven membrane micro-

The closure of the closure, and the efficiency of repeated operations up to 30 times. Thus, the film-type aerodynamic micro-valve, the use of inlet pressure control, appropriately increase the aspect ratio of the controlled liquid channel, you can effectively and accurately achieve the switch control and flow control.

5. **Valve diaphragm deformation and airway flow field relationship**

Because the PDMS material used in the diaphragm is a mixture of organosiloxanes with chain structures of different degree of polymerization, it has the structure of high elasticity and also has a certain breathability. Scanning electron microscopy was used to observe the cross-sectional morphology of the PDMS film. It was found that the PDMS homogeneous coating structure, the temperature gradient in the micro-channel, and the local pressure change on the hydrophobic surface all affect the permeability of the valve membrane and finally the flow inside the micro-valve Field characteristics.

5.1. **Speed**

In this paper, when the inlet pressure is 5000 Pa, the gas flow characteristics in the micro-channels are analyzed. As shown in Fig. 9, as the valve membrane warps upwards, while changing the cross-sectional shape of the flow passage, a partial vacuum is generated inside the air passage close to the membrane so that the air flow is partially entrained by the vacuum when it is moved below the membrane Form a counterclockwise gas swirl. Further studies showed that with the increase of inlet pressure, the gas vortex intensity under the diaphragm gradually increased, the range of action gradually expanded, the gas slip velocity near the diaphragm increased, the Reynolds number inside the airway was controlled, and the degree of turbulence was enhanced.
As shown in Fig. 9, as the valve membrane warps upwards, while changing the cross-sectional shape of the flow passage, a partial vacuum is generated inside the air passage close to the membrane so that the air flow is partially entrained by the vacuum when it is moved below the membrane forming a counterclockwise gas swirl. Further studies showed that with the increase of inlet pressure, the gas vortex intensity under the diaphragm gradually increased, the range of action gradually expanded, the gas slip velocity near the diaphragm increased, the Reynolds number inside the airway was controlled, and the degree of turbulence was enhanced. Due to the existence of the gas vortex below the diaphragm, the gas flow path has obvious speed difference. The gas flow velocity is the lowest at the center of the gas vortex. The outlet velocity from the gas swirl center to the gas flow path gradually increases and reaches the maximum value.
Figure 10. Velocity characteristics in gas channel with different inlet pressure

Further studies show that as the inlet velocity increases, the vortex range of the gas gradually increases and occupies the entire cavity; the position of the gas vortex center gradually moves away from the gas inlet and the formation speed of the gas vortex is faster. As can be seen from Fig. 10 a), the gas flow rate at the center just below the diaphragm in the gas flow path increases with inlet velocity as the inlet gas velocity increases. As shown in Fig. 10 b), it can be seen that with the increase of inlet velocity, the velocity of air in the airway decreases obviously. And as the inlet velocity increases, the velocity decreases more. The flow velocity near the inlet of the gas channel descends more slowly and the velocity near the outlet increases rapidly.

5.2. Pressure

Figure 11. Pressure distribution along gas channel when inlet pressure is 1.26 kPa

As can be seen in Fig. 11, the pressure in the gas passage decreases first and then increases and then decreases slightly. The main reason for the pressure change is caused by the pressure difference between inside and outside of the gas vortex. The pressure below is asymmetrically distributed and the pressure near the airway exit is greater.
**Figure 12.** Pressure characteristics in gas channel with different inlet pressure

As can be seen from Fig 12. a), as the inlet air velocity increases, the pressure in the air passage increases gradually. As Fig 12. (b) shows, the pressure fluctuation in the air passage becomes more pronounced as the inlet pressure increases.

5.3 Diaphragm force analysis

In this paper, the deformation and stress analysis of the elastic diaphragm in the middle of the micro-valve are studied respectively under the two different driving modes of air inlet and velocity inlet.

![Stress and Strain Tensors](image1.png)

**Figure 13.** Stress and strain of valve diaphragm with inlet velocity 100 m/s

As can be seen from Fig 13, under the inlet speed, the central area of the diaphragm is pushed upwards to squeeze the fluid passage. The two ends of the diaphragm are respectively subjected to tensile stress near the airway side and the compressive stress near the side of the liquid channel. Straight direction to form a shear effect.

![Stress and Strain Tensors](image2.png)

**Figure 14.** Mechanical characteristic of valve diaphragm with different inlet pressure

From Fig 14 (a), it can be seen that the stress acting on the two ends of the diaphragm gradually increases with the increase of inlet velocity, and the greater the inlet driving velocity, the greater the stress gradient at the edge. The strain tensor of Fig. 14 (b) further adds that the smaller the inlet velocity...
is, the smaller the overall strain of the valve in the vertical direction is. However, as the inlet velocity increases, the steady area of the valve center increases. However, the strain at both ends changed drastically, an increase of 7 to 10 times over the central area. This shows that the increase of inlet speed will aggravate the stress concentration on the edge of the diaphragm, which will easily cause the fatigue of the diaphragm of the valve.

![Stress tensor](image1)

![Strain tensor](image2)

**Figure 15.** Stress and strain of valve diaphragm with inlet pressure 0.7 kPa

It can be seen from Fig. 15 that under the inlet pressure, the central region of the diaphragm is pushed upwards to squeeze the fluid channel. The two ends of the diaphragm are respectively subjected to tensile stress near the airway, and the diaphragm near the fluid channel is under compressive stress. The whole piece of the tensile stress, the diaphragm near the central part of the gas channel by the local compressive stress.

![Stress](image3)

![Strain](image4)

**Figure 16.** Mechanical characteristic of valve diaphragm with different inlet pressure

The pneumatic diaphragm valve at 0~200m / s inlet pressure on the diaphragm analysis. As shown in Fig. 16, during the deformation of the planar film, stress on both ends of the film is relatively large, which is the main reason that the two ends of the film fail to rupture. As the inlet velocity increases, the
stress at both ends of the planar film increases sharply, while the stress in the rest increases slightly. In terms of strain, increasing the driving pressure and increasing the starting speed have basically the same changes on the strain of the valve diaphragm, which are all stable in the central region, and the strain at both ends of the diaphragm increases with the inlet pressure. This can be understood as both a velocity inlet and a pressure inlet, in fact, the source of the initial energy, the enhancement of the energy of the driving source, the increase of turbulence in the change of the internal flow in the airway, The energy transfer and exchange become more complex, the effect of the diaphragm is also more and more effective, and this effect due to the structural characteristics of the diaphragm determined, the diaphragm will play a role in the destruction of the impact of micro Valve life. Therefore, to improve the effectiveness of micro-valve control at the same time, we must fully consider the pressure resistance of the diaphragm to ensure control effectiveness.

6. Experimental program and effect
In order to further verify the above analysis is true and reliable, this paper designs and designs the test device as shown in Figure 17 to validate the effectiveness of the pneumatic micro-valve driven by different speed inlet and pressure inlet respectively.

![Test principle and device](image)

**Figure 17. Test rig**

According to Figure 17 a) Test Schematic Figure 17, b) set up the experimental test device. The controller adopts Wen-Chou chip company WH-PMPP-12-type constant pressure pump. Liquid channel outlet flow measurement OMEGAdpg120-type flow meter. This paper tests the different inlet velocity (500,1000,1500,2000) μL/min, the flow channel with the control of the gas channel can achieve a clear flow control effect, as shown in Figure 18.

![Micro valve open and closed](image)

**Figure 18. Operating performance of pneumatic micro valve**
Figure 19. Control effect of velocity inlet

As shown in Fig 19. At the same air supply rate, the degree of liquid channel closure gradually decreases as the liquid flow rate increases. At the same liquid flow rate, with the increase of gas supply rate, the degree of liquid channel closure gradually increases, and the increasing speed increases first and then decreases.

In this paper, we test the pressure flow characteristics and shutdown response characteristics of micro-valves with different diaphragm area.

Figure 20. Pressure flow characteristics of diaphragms with different cross sections under different driving modes

As shown in Fig 20, a wide width with a large actuation area can withstand a relatively large hydraulic pressure at the same control pressure. This case can be explained for the following reason. When the control pressure is applied to deform the elastic film to cut off the flow path, a part of the applied control pressure is used to counteract the stress caused by film deformation and the remaining part is used to resist the passage in the liquid passage Hydraulic. Due to the same channel depth, the deformation rate of the film (the linear ratio in the direction of deformation before and after the deformation) is larger for a narrower liquid passage, and in this case, a larger partial pressure is required to counteract the film.
deformation Stress, and can be used to resist the partial pressure of the hydraulic pressure correspondingly reduced, making the micro-valve of the critical pressure value becomes smaller.

7. Conclusions
In this paper, passive gas brake flow control micro-valve to complete the following research work:

(1) The gas flow problems for micro and nanoscale channel, analyse the internal air flow characteristics of the micro-valve, is obtained based on the given two-dimensional augmented Burnett equations, a clear boundary conditions considering creep effect under micro-nano scale, A relaxation method is introduced to increase the computational stability. The elastic solid nonlinear equation is used to describe the stress in the process of structural deformation, and the formulas for calculating the pressure and the viscous force of the liquid subjected to the deformation of the film structure are given.

(2) The velocity and pressure variation of the velocity inlet to the micro-valve internal flow field are analyzed numerically. The results show that with the increase of the supply pressure, the horizontal velocity in the gas flow path below the valve diaphragm decreases, and the kinetic energy of the gas partially transforms to the rotational kinetic energy of the gas at the cavity. With the increase of inlet velocity, the position of swirling vortex center in airway gradually moves away from the gas inlet, and obvious pressure drop phenomenon occurs near the outlet of gas film. At this time, the energy of the gas is mainly represented by the rotational kinetic energy of the gas at the cavity.

(3) Combining experiments, this paper analyzes the working effect and pressure flow characteristics of flat-diaphragm pneumatic micro-valves under different driving modes. The results show that the pressure-driven method is more likely to produce a stronger gas vortex below the diaphragm, resulting in the pressure difference between the inside and outside of the diaphragm to push the diaphragm to cut off the liquid passage, thus having a better control effect. Under the pressure-driven mode, the stress and strain on both ends of the diaphragm is small, and the diaphragm is not easily damaged.6. Patents
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