# Numerical Simulation of Axial-flow Labyrinth and Piston Regulator Based on CFX

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## Abstract

**Axial-flow regulator is an important device to secure the pipeline gas delivery, Although the device has the advantages of large flow and compact structure, high gas flow rate would produce strong erosion to spool and internal component in high pressure difference, In order to improve the performance of the regulator, its main valve structure is optimized , designed a new type of gas regulator which combine labyrinth regulator and piston regulator, it has compact structure and large flow and multistage decompression advantage. Modeling whole structure use 3D software, numerical simulation of the structure based on CFX and get the visualization of the flow field, the result show that pressure distribution is more uniform in this design, this equipment can work in high diffident pressure and performance is further improved. It's effect obvious and can meet the expected target.**

## Keywords

**Labyrinth regulator, Piston regulator, Multistage decompression, Flow field analysis.**

## 1. Introduction

Regulator is a device which can keep natural gas has a constant pressure in the outlet by changing the flow rate, which performance has a direct impact on the stable operation of the town gas. When high pressure difference gas passed through the regulator in the actual production, the complex vortex and disturbance will be produced in the throttle, this will produce cavitation, erosion, mechanical vibration and noise, and it will lead to damage to the internal structure of the valve, it is likely to cause wear of piping system [1,2], to solve this problem, multi stage decompression is used when choosing high strength and wear resistance of the material, this method is mainly divided decompression into multi stage. The velocity and pressure are controlled by a particular runner, gas flow rate is controlled by controlling the flow channel area and the throttle series, and it will reduce the noise and prevent liquid cavitation, the life of the regulator is greatly improved in the harsh working condition [3]. Mcghee J used the fluid kinetic energy to measure the valve outlet energy, in order to prevent vibration the kinetic energy of fluid at the outlet should be less than 480KPa[4,5]. The DRAG® Atmospheric Resistors developed by CCI Corporation used multistage channel to avoid the high pressure drop when the gas into the flow channel and generate noise [6]. Sanjay V Sherikar and Arun Puri had described the DRAG valve speed control principle, approximately 5% of the total energy of the fluid in the labyrinth channel is dissipated to prevent cavitation, vibration and noise generation [7]. Leimkuehler B had described using a combination of different forms of labyrinth disc channel can form different flow coefficient [8], Chen Zuoxuan had carried on the steady state simulation to the MX-6L25W1V-0 type minimum flow valve, and obtained the pipeline interior different surface roughness has little effect on the blood pressure effect[9], Yao Wuping used CFD method to calculate the flow field of labyrinth channel, and the accuracy of the flow calculation method was verified by the experiment data at room temperature and atmospheric pressure[10]. At present, all design of the regulator adopts the traditional calculation formula, which makes the internal flow field of the regulator less visible, it can not directly determine the merits of the design, it is difficult to effectively ensure the smooth running of the regulator [11]. This article from the perspective of numerical simulation, combined with the characteristics of labyrinth regulator and piston regulator on the basis of relevant information, using the CFX method to simulate the flow characteristics of the internal medium of the axial flow labyrinth piston regulator, to get visualization results about regulator internal flow[12], Through the study the internal pressure of regulator, the velocity distribution and pressure drop characteristics, analysis of different series disc quality, through the optimization of flow field analysis for the main valve structure optimal flow field performance, provide the basis for further optimization of the axial flow type pressure regulator, which can meet the treatment effect of high flow, high pressure in the ring under the harsh environment, it can provide the theory basis for the axial flow type gas regulator manufacturing and reference for similar applications.

## 2. Structure of labyrinth piston regulator

According to the current direct force type pressure regulator are not very good use of the status under the condition of high pressure large flow rate, probes into the current direct type pressure regulator for design improvement, designed a axial labyrinth piston gas regulator which makes it able to work under high pressure, large flow conditions. Axial flow labyrinth piston regulator is divided into two stage, the first stage is labyrinth decompression and the second stage is the piston decompression. The labyrinth disc as a special decompression structure, it has very good decompression effect and has a very high life expectancy in harsh environments. Its internal media through the specific shape of the flow channel, and collision with labyrinth wall to change the flow direction, reduce the gas pressure energy, resulting in gas expansion, in order to achieve the purpose of lowering decompression, the labyrinth disc structure is mainly composed of a plurality of bend, gas will have a decompression after each bend, In the design of labyrinth disc, channel will increase accordingly after through each bend, In addition, due to the compressible flow density is not a constant value, when the gas expansion, its density decreases and the gradual expansion of the flow channel is conducive to ease the pressure caused by the expansion of gas, to reduce the impact of the unstable medium on the internal components of the valve body, so that the internal pressure is more uniform, the flow rate is more stable. The design of channel structure is shown in figure 1.

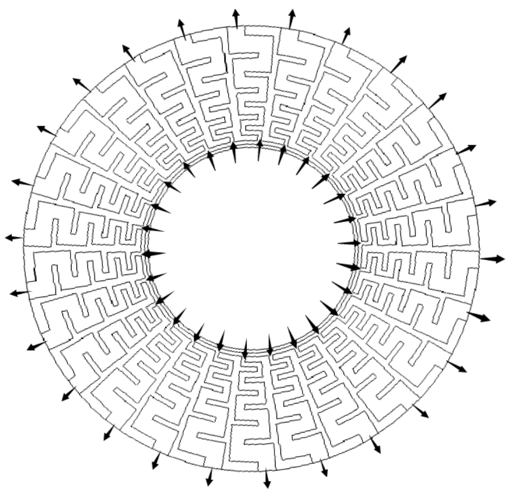

Fig.1 Flow path of labyrinth disk

The second stage of decompression is through the movement of the piston valve to adjust the opening of the valve port to complete the pressure once again reduced, the valve port is provided with a strip groove on the annular cylinder. The structure not only can avoid the generation of noise during the process of pressure reduction, but also hedge through the gas of the strip groove. It will be conducive to the reduction of gas velocity, in this process, the gas hedging will put part of the kinetic energy into internal energy, it will make the internal temperature rise, make up for the sudden drop in the temperature caused by the decompression expansion, the generated energy can reduce the generation of the gas hydrate in the valve core, to ensure the stability of the gas pipeline network and the service life of the voltage regulator, and achieve the ultimate goal of design [13].

The design of the labyrinth piston regulator structure is shown in Figure 2[14]. Consult Bernoulli equation, this paper made theoretical derivation for the design of the pressure regulator labyrinth disc under the condition of medium for compressible gas, including the determination of labyrinth disc series of turning, the number of labyrinth flow channel, and the number of labyrinth disc, and reference documents, ensure the size of the entrance labyrinth disc according to reference documents, etc. Using 3D modeling software to build structure model, in order to achieve the decompression of high pressure, the first stage of labyrinth disc step-down structure will achieve entrance 4MPa to export 0.8MPa, It is composed of a plurality of labyrinth disc folding, so it can increase the disk to ensure the hypotensive effect of series, the second stage decompression structure will realized entrance 0.8MPa to export 0.2MPa, The opening of the valve port is controlled by the stroke of piston to achieve further decompression, The special structure design of the second stage decompression has de-noise and steady flow function, it will ensure the stability of the outlet pressure.

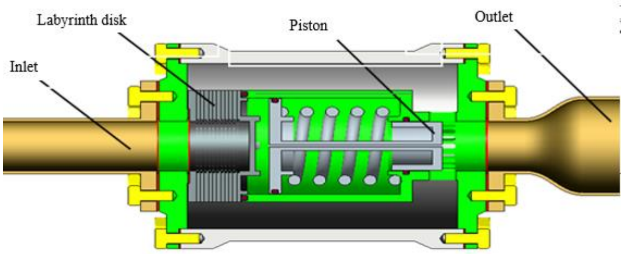


Fig.2 3D model of axial-flow labyrinth piston regulator

## 3. FEA of axial-flow labyrinth piston regulator

The 3D model is simplified and it can reflect the real structure of the internal flow channel of the regulator. The straight pipe section of regulator has a large influence on the flow field, in order to eliminate the influence of the internal flow field of the valve body to ensure the full development, the length of the inlet and outlet pipe is five times pipe of the diameter, to get flow-path in regulator and analyze the whole 3-D model, the flow path shown in Figure 3.

Fig.3 Whole internal flow path

The flow path of labyrinth disc is shown in Figure 4, In order to ensure that gas can be reduced rapidly in a relatively short time and in a short channel, there are 26 flow path in each labyrinth disc, this structure ensure inlet velocity is more uniform and stable, flow will divide equally by many path, so pressure and speed fall continuously, and the flow in each path non-interfering under the premise of throttle step-down, to avoid violent vibration of the valve body because of disturbance.

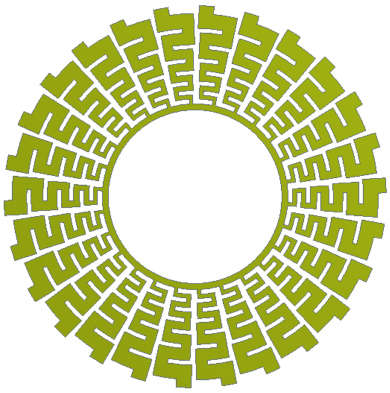

Fig.4 Internal flow path of labyrinth disk

Whole flow path model is shown in Figure 3, grid division in the software of ANSYS WORKBENCH, local encryption in labyrinth disc and piston type valve core outlet, the mesh is completed as shown in Figure 5. Because the structure is dedicated to the high pressure difference and flow velocity in gas pressure reducing, so choose gas as work medium and boundary conditions set approximate real conditions, according to the initial target setting fluid inlet pressure is 4MPa, the outlet pressure is 0.2MPa, choose k-ε as turbulence model and choose convection model as up-wing, start the analysis of the solution after choose completion [15].

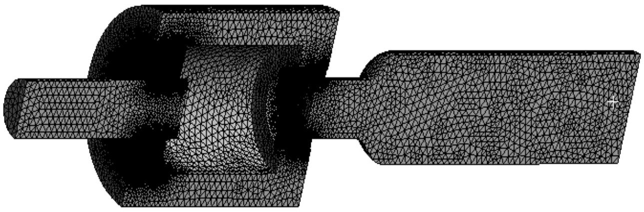

Fig.5 Internal grid of axial-flow regulator

## 4. Numerical simulation results

The analysis of finite element to verify the pressure regulator is designed to meet the design requirement, in this paper, through finite element simulation results we can look for different number of disks and compare which combination is more suitable. Internal pressure distribution of axial flow labyrinth piston regulator shown in Figure 6, from this picture, it had reached the design value after two stages of pressure reduction, as medium through the labyrinth structure gas pressure drop from 4MPa to 0.8MPa and pressure drop smoothly, it can change pressure reduce effect by increase labyrinth disk. observed the change of pressure drop near labyrinth disc,it can be found the pressure is always within a reasonable range, so it can avoid the generation of cavitation, the second stage put pressure from 0.4MPa to 0.02MPa when gas pass postion, the internal pressure distribution is even and it meets the pressure drop at the same time. To summarize, the pressure distribution is more uniform from inlet to outlet, the pressure drop is relatively smooth and the outlet pressure is stable within a certain range, so this structure can ensure the normal operation of the gas transmission.

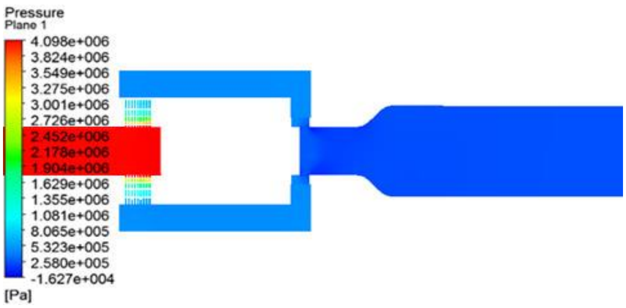


Fig.6 Internal pressure distribution of regulator

Internal velocity distribution of axial flow labyrinth piston regulator shown in Figure 7, and Internal velocity stream distribution is shown in Figure 8, from Figure 7 can find gas velocity will increase steadily as pressure drop in every stage of decompression, as gas pass piston the velocity does not exceed sonic velocity because the special structure design, so the noise reduction effect is obvious, the advantage of this structure is that after each decompression the speed of the small area can reach a stable value, and the velocity of overall structure is more smooth. Observation figure 8 can be found, the gas will show a spiral trend when pass labyrinth channel, which led to the asymmetry of the exit speed.

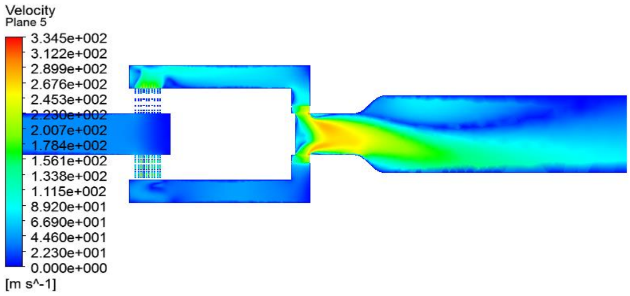


Fig.7 Internal velocity distribution regulator

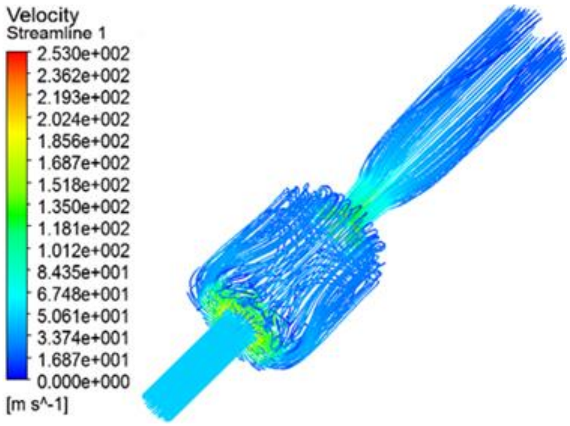


Fig.8 Internal velocity stream of overall regulator

Internal temperature distribution of axial flow labyrinth piston regulator shown in Figure 9, from Figure 9 can find in the position of maximum velocity has minimum temperature, because the hedge effect occurred at throttling mouth of piston type valve core, then kinetic energy is converted into internal energy and the temperature is increased slightly, the lowest temperature appears in the different diameter joint, in this section the velocity increase because of flow path expansion, so the temperature sudden drop, but the temperature range will not produce hydrate and it will not affect the normal operation of the gas pipe network.

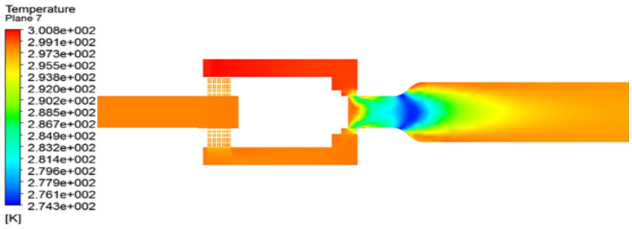


Fig.9 Internal temperature distribution of regulator

In order to further explore the labyrinth disc series effects on pressure drop effect and reduce the spiral trend of gas at outlet, so selected ninth tenth and eleventh disc to analysis, choose 29 points in flow path of each labyrinth disc to analyze pressure drop and temperature, there are pressure drop and velocity in fifth disk in different stages as shown in Figure 9 and Figure 10, it can be found pressure drop is obvious as disk stage increase, the pressure drop is higher and later it become stable, so the more number of disk stage the decompression effect is better as at the same pressure inlet and the same mass flow rate outlet. Similarly, the flow rate is not the same in different flow path, the less number disk stage the faster velocity as at the same pressure inlet and mass flow rate outlet, and the more easily occur spiral trend and noise.

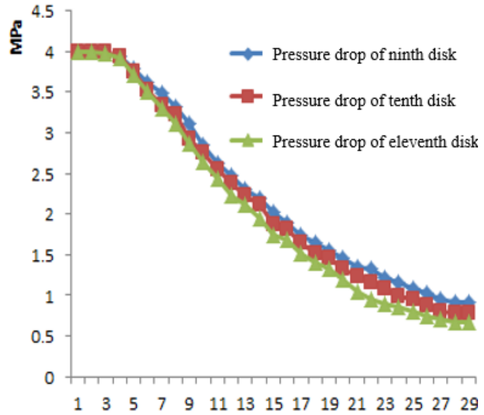


Fig.10 Pressure drop in fifth disk of different stage

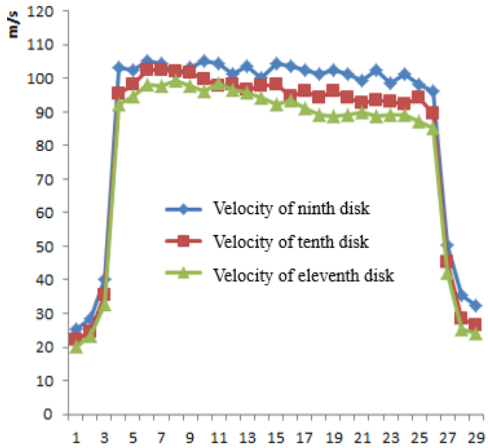


Fig.11 Velocity in fifth disk of different stage

## 5. Conclusion

Using three-dimensional modeling software Pro/E to set up the 3D model of the designed pressure regulator, and import the model into the finite element analysis software ANSYS CFX for flow field simulation after simplified the model. The analysis of finite element to verify the pressure regulator is designed to meet the design requirement, in this paper, through finite element simulation results we can look for different number of disks and compare which combination is more suitable. There are some shortcomings in the structure which can be seen through the simulation, the structure needed further improvement. The result of ANSYS WORKBENCH show that pressure distribution is more uniform in this design, the equipment can work in high diffident pressure and the performance is further improved, it's effect obvious and can meet the expected target. The maximum flow rate of the regulator can be effectively reduced because it has two decompression stage, it adopted multi path at each disk in the first stage, which could reduce eddy intensity and area, the internal pressure would more uniform and velocity stream more fluid, its performance increase greatly. In the second stage adopt the piston structure to fit the ring groove, internal energy generate by gas collision, it will reduce the gas flow rate and avoid the noise caused by the disturbance, at the same time to inhibit the production of hydrate. Therefore, the design of the multi-stage decompression structure can meet the demand of high pressure difference and large flow, and this method can provide reference for the design and research of similar equipment.

As an important part of the urban gas system regulator provides the possibility for the transportation and the use of natural gas, but in most of domestic pressure research in this field is given priority to with generic, several processing and prototype test of the development cycle increase the cost greatly, hardly conducive to the improvement of technology innovation. Study also mostly stay in principle analysis or test phase, especially for high pressure difference regulating valve under the condition of internal compressible flow almost no in-depth research, which unable to provide effective reference.

according to the current direct force type pressure regulator are not very good use of the status under the condition of high pressure large flow rate, probes into the current direct type pressure regulator for design improvement, designed a axial labyrinth piston gas regulator which makes it able to work under high pressure, large flow conditions. This type regulator can directly reduce the gas from the high pressure A to the medium pressure B according to “Code for Design of City”, it will greatly reducing the tedious process of traditional gas decompression, so axial-flow labyrinth and piston regulator can meet the application of the pressure reducing effect in many towns and cities.

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