Finite Element Analysis of New Downhole Throttle Based on Orifice Valve

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Abstract. In order to realize the intelligentization of downhole natural gas intelligent gas production technology, a set of downhole intelligent throttles suitable for remote control was designed. This article describes the mechanical structure design and remote-control mechanism of smart throttle. Using ANSYS finite element analysis software, the mechanical structure of underground intelligent throttle is analyzed and the fluid field of key parts of throttle is analyzed. According to the finite element analysis results, the mechanical design of the throttle satisfies the requirements and can provide equipment support for the implementation of downhole natural gas intelligent gas recovery technology. Finally, through the simulated well test, the feasibility of the throttle design was verified.

1 Introduction
In recent years, in order to meet the intelligent development of underground natural gas intelligent talents, researchers have been eager to carry out research on the throttling process and the intelligentization of throttling devices [1]. Advanced downhole process technology has become more and more automated, and the downhole throttle control tool can be remotely controlled through the operation on the well. However, the development of domestic underground intelligent throttling devices is relatively slow, and the finished product of new-type downhole intelligent tools is not high. Therefore, it is increasingly important to research and develop autonomous intelligent throttling tools. The main application of throttling in the domestic natural gas production industry is active and fixed pure mechanical downhole throttles with throttling nozzles [2]-[3]. The biggest drawback of this type of restrictor is that it cannot adjust the size of the nozzle diameter according to the real-time demand, and it must be salvaged through the salvage tool. Manual adjustment of the tool is then placed in the downhole, and the time-consuming adjustment process is severe and economical. not tall. Therefore, the development of intelligent throttling tools to control the production of borehole diameter through remote operation will be the trend of the development of natural gas technology in the future.

2 New Intelligent Throttle Mechanical Structure

2.1 Mechanical design
The downhole intelligent throttle aims at realizing the remote control of the communication signal and adjusting the aperture size of the throttle using computer control technology, automatic control theory and modern signal processing technology [4]. However, the mechanical structure is the carrier of the intelligent control of the throttle. Therefore, it is necessary to analyze the mechanical structure of the
throttle. The mechanical structure of the throttle as shown in Figure 1.

![Throttle mechanical structure](image)

1. Air inlet; 2. Valve seat; 3. Static valve; 4. Flap; 5. Transfer sleeve one; 6. Transfer sleeve two; 7. Drive motor; 8. Air guide tube; 10. Retainers; 11. Heads; 12. Female sets.

**Figure 1.** Throttle mechanical structure

Throttle structure is mainly composed of motor transmission mechanism, electrical structure, orifice valve body, pressure wave acquisition system and sealing structure. The transmission mechanism formed by the motor and the speed reducer controls the supporting valve structure of the intermediate transmission mechanism to control the rotation of the valve flap. After the natural gas passes through the air intake nozzle, it passes through the air-guiding channel between the electric sealing cylinder and the air-guiding tube after throttling and flows out from the end of the female sheath. There is a uniform flow hood in the female sleeve, and the gas flows out through the common flow hood after passing through the end of the throttle valve.

### 2.2 Design calculation methods

The orifice is designed with an orifice plate valve. The valve flap is divided into two parts, the flap and the static valve. The schematic diagram of the orifice valve structure is shown in Figure 2.

![Orifice valve structure schematic](image)

According to the existing method for calculating the throttle diameter of the throttle [5], the diameter of the nozzle of the throttle can be obtained through the judgment formula of the gas frontage state and the mouth flow equation:

\[
\frac{P_1}{P_2} = \left( \frac{2}{k+1} \right)^{\frac{k}{k-1}}
\]  

(1)

When \( \frac{P_1}{P_2} \leq \left( \frac{2}{k+1} \right)^{\frac{k}{k-1}} \) is satisfied, the current state is the critical flow state, the gas flow through the throttling nozzle reaches a maximum, and the production is:

\[
q_{\text{max}} = \frac{0.408 \rho_d d^2}{\sqrt{T_{\text{ref}} Z_1}} \left[ k - 1 \left( \frac{2}{k+1} \right)^{\frac{2}{k-1}} - \left( \frac{2}{k+1} \right)^{\frac{k+1}{k-1}} \right]
\]

(2)

When \( \frac{P_1}{P_2} > \left( \frac{2}{k+1} \right)^{\frac{k}{k-1}} \) is satisfied, the current state is non-critical flow state, the gas flow through the
throttling nozzle reaches a maximum, and the production is:

\[
q_{sc} = \frac{0.408 p_1 d^2}{\sqrt{r_1 T_1 Z_1}} \sqrt{k - 1 \left[ \left( \frac{P_1}{P_2} \right)^{\frac{2}{k+1}} - \left( \frac{P_1}{P_2} \right)^{\frac{k}{k+1}} \right]},
\]

(3)

Where \(q_{sc}\) and \(q_{max}\) represent the natural gas volume flow through the throttling nozzle in critical and non-critical states, respectively \((10^4 \, m^3 / \, d)\); \(p_1\) indicate the pressure at the entrance of the nozzle before throttling and \(p_2\) indicate the pressure at the throttle after throttling \((MPa)\); \(d\) is the nozzle aperture diameter \((mm)\); \(T_1\) is the temperature at the inlet of the nozzle before throttling \((K)\); \(Z_1\) is the gas deviation coefficient of throttling nozzle at \(T_1\) and \(P_1\); \(r_\gamma\) is the relative density of natural gas; The natural gas adiabatic coefficient is \(k\), General value \(1.25 \sim 1.30\).

Considering the actual situation, the throttling nozzle is set to operate in a critical state. According to (2), the diameter of the throttling nozzle can be determined as

\[
d = \sqrt[21]{\frac{q_{max}}{0.408 p_1}} \sqrt{\frac{r_1 T_1 Z_1}{2 \left( \frac{2}{k+1} - \frac{2}{k+1} \right)^{k+1}}},
\]

(4)

As shown in Figure 2, above, the nozzle area is calculated as \(\frac{\pi d^2}{4} = \frac{2 \pi \alpha}{360} (r_1^2 - r_2^2)\), Where \(r_1\) is the outer radius of the sector area, \(r_2\) is the sector area inner radius, and \(\alpha\) is the angle between the moving valve flap and the static valve flap.

### 3 Analysis of the main results

This paper uses ANSYS finite element analysis software to perform mechanical analysis and flow field analysis of the downhole intelligent throttle, and to simulate the working environment of downhole tools. Through the simulation analysis results, improve the mechanical structure, so that the structure can work better in the harsh environment downhole [6]-[7].

#### 3.1 Static analysis

The downhole working environment is rather harsh, so it must be ensured that the restrictor can work in the high temperature and pressure environment downhole. Due to the limitations of downhole working space and the fragility of electrical structures, this paper uses ANSYS finite element analysis software to perform static analysis of downhole intelligent throttle [8]. Mainly on the electric seal tube and air tube in the high temperature and high pressure static analysis and modal analysis. The static analysis includes the stress and strain data, as shown in Figure 3 and 4. The modal analysis refers to the natural frequency and vibration shape of the mechanical structure, as shown in Figure 5.

**Figure 3.** Strain and stress cloud diagram of electric seal barrel in static state
Figure 3 shows the strain and stress cloud diagram of the electric seal barrel in static state. It can be seen from the figure that the maximum stress of the electric seal barrel is 1813.6 MPa. The maximum deformation is 0.072947 mm, which occurs at the end of the electric seal barrel. In addition, the deformation of the outer wall of the seal barrel is also different. Figure 4 shows the static state strain and stress cloud diagram of the air-conductor. It can be seen from the figure that the maximum stress of the air-guiding tube is 829.77 MPa. The maximum deformation is 0.13174 mm.

Figure 4. Strain and stress cloud diagram of air-guiding tube in static state.
The above figure shows the modal analysis of the throttle section. When the throttle is working downhole, high-speed eroding of the air flow will generate vibration. When the frequency is too high and reaches the natural frequency, resonance will occur. The modal analysis can obtain different natural frequencies. In the case of vibration, the figure above shows two natural frequencies. The first natural frequency is 37.144 Hz and the second natural frequency is 247.17 Hz. The structure oscillates only slightly at the first natural frequency; the second natural frequency swings significantly, mainly due to the distortion of the electrically sealed bucket. Combined with downhole vibration, it can be analyzed that the throttle can work normally downhole.

3.2 Flow field analysis
According to the actual parameters and technical requirements of gas wells in the Sichuan-Yunnan region [9], the internal diameter of the natural gas pipeline is 62mm, the pressure at the inlet of the throttle is 35MPa, the outlet after the throttle is 7MPa, and the throttle is placed in the ground at a distance of 2000m below the ground. The formation temperature is 90°C; the natural gas relative density is 0.85, the gas compression coefficient is 0.7, and the adiabatic coefficient is 1.25.

As shown in Figure 6, the set value of the pressure at the inlet of the throttle valve is 35 MPa. Through the throttling effect of the throttling nozzle, the flow rate of the gas in the channel increases rapidly and the pressure drops rapidly as the area inside the pipeline decreases rapidly. The pressure area in the channel rises, and the pressure change tends to be stable [10]-[11]. After the throttling is over, the pressure value is stabilized at about 7MPa, and the throttling process is completed.
As shown in Figure 7, the figure shows the speed change cloud diagram of the front end of the throttle. It can be seen from the figure that the speed change of the gas in the channel before and after throttling occurs, and the gas undergoes sudden expansion and sudden flow during the flow. During the shrinking process, the speed suddenly increases near the orifice, and the maximum speed reaches about 210~240 m/s. After the throttling effect of the throttling nozzle, the area inside the throttle pipe suddenly increases and the speed decreases. Finally stabilized at around 20 m/s.

4 Conclusion
The new type of orifice plate valve wireless smart festival was tested in a simulated well by testing the overall tightness of a new type of orifice valve wireless smart throttle, the stability of electrical components operating at high temperatures, and the stability of pressure waves transmitted under high temperature and high pressure. The flowmeter has achieved good stability under various experiments. At the same time, the downhole intelligent throttle can provide equipment support for the implementation of downhole intelligent throttling technology and has reference significance for the development of relevant intelligent downhole tools.

References
[1] Yan D, Qing D, Li L, et al. Numerical Simulation of Throttle Valves with Different Spool and Valve Body by Fluent 2011 J Mechanical Engineering & Automation, 111.
[2] HAN, Dan-xiu, LI, et al. Adaptability Study of Intelligent Well Systems in East China Sea Oil Field 2008 J International Journal of Plant Engineering & Management 13(4) 205-213.
[3] Hu G, Zhang P, Wang G, et al. Performance study of erosion resistance on throttle valve of managed pressure drilling 2017 J Journal of Petroleum Science and Engineering 156 29-40.
[4] Duan B, Liu L, Xu X, et al. Research and application of steel wire free dropping and fishing downhole chock 2011 J Oil Drilling & Production Technology 1 046.
[5] Wang X, Economides M. Advanced natural gas engineering 2013 M Elsevier.
[6] Zhang Z, Hao Y. Research and application of downhole throttling technology in Yulin gas field 2009 J Oil Drilling & Production Technology 1 038.
[7] Scheaua F D. Functional description of a hydraulic throttle valve operating inside a hydraulic circuit 2016 J Hidraulica 1 47.
[8] He M G, Ma F M et al. Design and Flow Field Analysis of Downhole Intelligent Throttle 2013 J China Petroleum Machinery 6 20.
[9] Yong X, Qian Y M, Yacong Y, et al. Development mode and surface supporting technology in the Changqing gas zone 2010 J Natural Gas Industry 2 029.
[10] Hou C, Qian J, Chen F, et al. Parametric analysis on throttling components of multi-stage high pressure reducing valve 2018 J Applied Thermal Engineering 128 1238-1248.
[11] Ashraf, Walid, et al. Effect of Replacement of Butterfly Throttle Body by Barrel Throttle Body on Mass Flow Rate using CFD 2017 R SAE Technical Paper 1 1078.