Engineering, 2024, 16, 38-45
https://www.scirp.org/journal/eng
ISSN Online: 1947-394X
ISSN Print: 1947-3931

Study on Characteristics of a High-Precision Cold Gas Micro Thruster

Zhaoli Wang, Changbin Guan, Xudong Wang, Weijie Zheng, Longfei Su

Advanced Space Propulsion Lab, Beijing Institute of Control Engineering, Beijing, China
Email: wangzhaoli_heu@163.com

How to cite this paper: Wang, Z.L., Guan, C.B., Wang, X.D., Zheng, W.J. and Su, L.F. (2024) Study on Characteristics of a High-Precision Cold Gas Micro Thruster. *Engineering*, **16**, 38-45.
https://doi.org/10.4236/eng.2024.161005

Received: December 31, 2023
Accepted: January 28, 2024
Published: January 31, 2024

Abstract

In order to improve the reliability of the spacecraft micro cold gas propulsion system and realize the precise control of the spacecraft attitude and orbit, a micro-thrust, high-precision cold gas thruster is carried out, at the same time due to the design requirements of the spacecraft, this micro-thrust should be continuous working more than 60 minutes, the traditional solenoid valve used for the thrusts can't complete the mission, so a long-life micro latching valve is developed as the control valve for this micro thruster, because the micro latching valve can keep its position when it cuts off the outage. Firstly, the authors introduced the design scheme and idea of the thruster. Secondly, the performance of the latching valve and the flow characteristics of the nozzle were simulated. Finally, from the experimental results and compared with the numerical study, it shows that the long-life micro cold gas thruster developed in this paper meets the mission requirements.

Keywords

High-Precision Micro Thruster, Performance, Flow Characteristic, Experiment

1. Introduction

In 21st century, various space nations and organizations have developed deep space exploration plans. Deep space exploration needs a long lifetime and high efficiency propulsion system.

With the development of science, space, aviation, navigation and land gravimetry have formed a complete system of earth gravity measurement. They complement and verify each other, which greatly improves the credibility and accuracy of the earth gravity field model. When using satellite gravity technology to acquire gravity data, it can acquire all-weather data. It has high efficiency, uniform base point, uniform resolution and accuracy. Satellite gravimetry can obtain the complete structure of the global gravity field, thus providing accurate gravity field and ocean circulation data support for resource exploration, environmental monitoring, precise navigation and other fields. In order to control satellite attitude, a micro-thrust, high-precision cold gas thruster is carried out. Surrey Space Technology Limited (SSTL) of the University of Surrey, UK, has made many achievements in the field of micro satellites, and has successfully launched many micro satellites of practical value, such as Alsat-1, UK-DMC, NlgerlaSat-1, BiSat-1 and so on. MOOG's cold gas propulsion system has been validated in CHAMP and GRACE satellite projects [1] [2] [3] [4] [5].

The micro cold gas thruster developed in this paper is used for control the spacecraft orbit, requiring that it should be continuous working more than 60 minutes. At the same time, due to the design requirements of the whole satellite, the power supply voltage is 21 V - 29 V. If the traditional solenoid valve is used for the thrust's control valve, the temperature of cold gas thruster will rise when the thruster long time working, in order to improve the reliability of the satellite propulsion system and realize the precise control of satellite attitude, a long-life micro latching valve was developed as the control valve of the micro gas thruster [6] [7] [8] [9]. The structure characteristics of the valve were analyzed. The performance of the latching valve and the flow characteristics of the nozzle were simulated. Finally, from the experimental results and compared with the numerical study, it shows that the long-life micro cold gas thruster developed in this paper meets the mission requirements [10] [11] [12].

2. Structure and Principle

The cold gas micro thruster mainly consists of inlet joint assembly, orifice plate assembly, fluid control valve, nozzle and so on, as shown in **Figure 1**.

2.1. Design of Fluid Control Valve

Fluid control valve adopts latching valve, the following aspects are mainly considered in the structural design of the latching valve:

In order to meet the requirement of miniaturization, the internal and external threads are cancelled in this latching valve, at the same time, permanent magnet

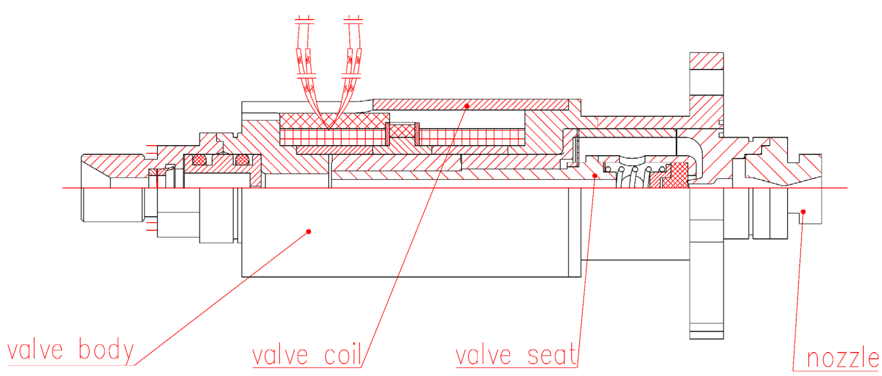

Figure 1. Schematic diagram of micro cold gas thruster structure.

locks are adopted.

The magnetic circuit structure of latching valve is suction type, and the latching valve is in suspension state by means of unilateral suspension. The friction between the moving parts and the valve body is avoided, and the friction-free suspension design of the product is realized.

The product has no self-contamination defects in the process of movement.

2.2. Nozzle Structure Design

Laval nozzle is used as the thruster's nozzle. Because this structure is easy and high reliability.

1) In order to achieve thrust accuracy, the orifice plate adjusting mechanism is set at the entrance of thruster to achieve thrust regulation.

2) In order to meet the requirements, a control baffle is set between the latching valve and the Laval nozzle to avoid the radiation of the latching valve by sunlight or cosmic particles.

According to the design specifications for the Laval nozzles, the following parameters are mainly selected based on comprehensive considerations of specific impulse, size, and other requirements:

- Specific heat ratio (K), 1.4 (N_2).
- Maximum working pressure, 0.17 MPa, P_1.
- Expansion ratio, 0.0006.
- Convergence angle, 2β (˚), 30˚.
- Expansion angle, 2α (˚), 30˚.

According formula 1 and 2, we got the throat diameter of the product calculated is 0.47 mm.

$$F = nC_F P_1 A_t \tag{1}$$

$$C_F = \sqrt{\frac{2k^2}{k-1}\left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}\left(1-\left(\frac{p_2}{p_1}\right)^{(k-1)/k}\right)} \tag{2}$$

In formula 1 and 2:

- n ------ correction factor.
- C_F ------ thrust coefficient.
- A_t ------ throat area.
- P_1 ------ inlet pressure.
- P_2 ------ outlet pressure.

3. Numerical Simulation of the Thruster

3.1. Simulation of the Latching Valve's Structure Strength

In order to assess the compressive strength of the latching valve, mechanical simulation was conducted on the inner cavity of the self-locking valve using finite element software. The simulation was conducted at an internal pressure of 0.8 MPa. After analysis, the maximum principal stress on the valve body was 4.6 MPa, which was far less than the yield strength of the material of 400 MPa, as shown in **Figure 2**.

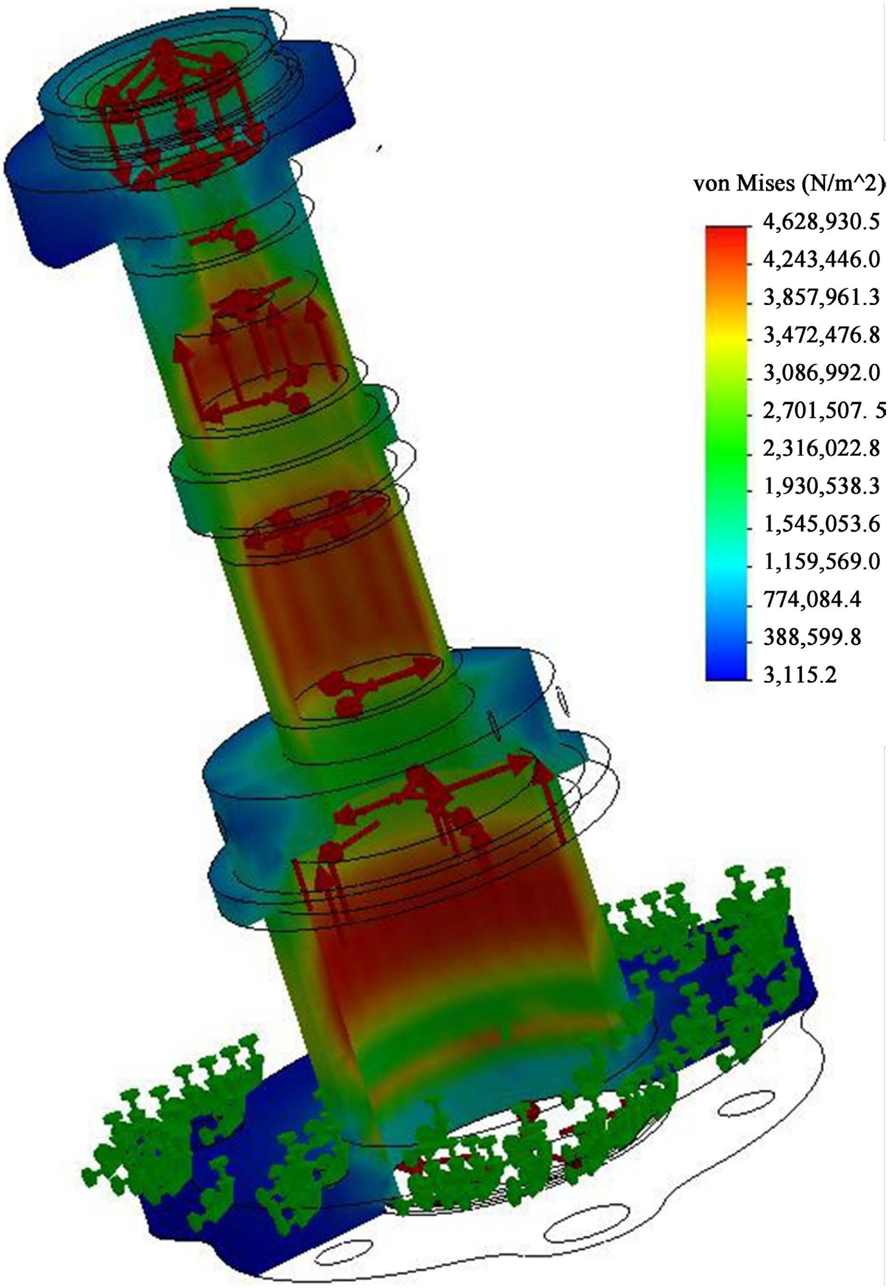

Figure 2. Strength analysis of valve body.

3.2. Simulation of the Latching Valve's Switching Performance

- Electromagnetic static characteristics simulation

The electromagnetic static characteristic of the latching valve is analyzed by the finite element analysis [13]. The static characteristic of the magnetic circuit mainly reflects the relationship between the initial suction and the electromagnetic force of the valve. It is used to determine the working point of the magnetic circuit of the valve. The static calculation result of the magnetic circuit of the product when the maximum working air gap is 0.4 mm is shown in **Figure 3**. 26 V is the rated design point of the working voltage, the initial suction of the valve is about 12.89 N. From the simulation results, it can be seen from the simulation results, it can be seen that compared to the load force of 0.301 N at the highest working pressure of 0.2 MPa of the valve, its opening margin is greater than 2.

- Electromagnetic dynamic characteristics simulation

During the whole movement of the armature, the load on the armature varies. The electromagnetic transient characteristics of the product at 26 V and 20˚C were simulated by finite element method. The results were shown in **Figure 4** and **Figure 5**.

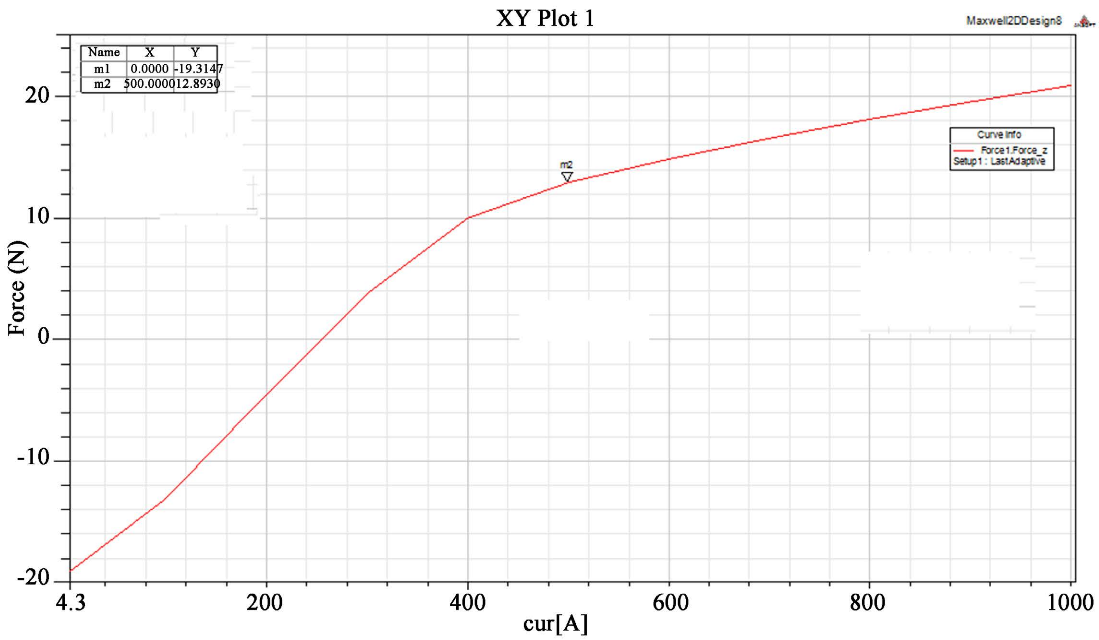

Figure 3. Static simulation result.

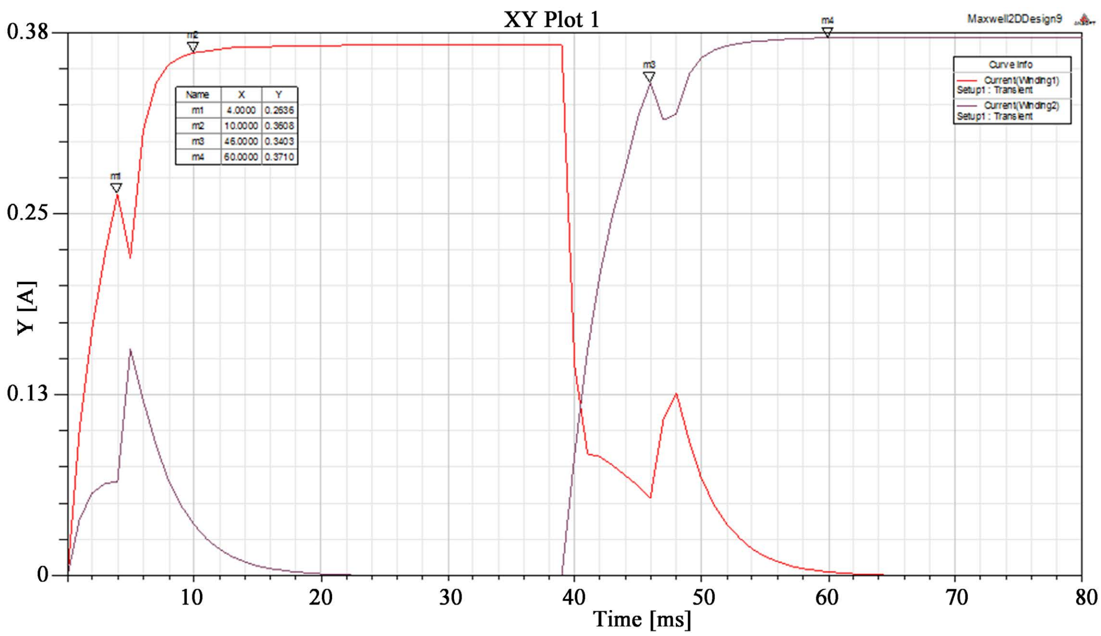

Figure 4. Switching response curve.

According to the above simulation results, we known that the switch reliability of the latching valve designed in this paper is sufficient, it can meet the operating conditions of the product in orbit.

- Simulation of the thruster's nozzle

According to the parameters obtained from formula 1 and 2, we use the CFD software Fluent simulated the performance of the Laval nozzle, the results were shown in Figure 6.

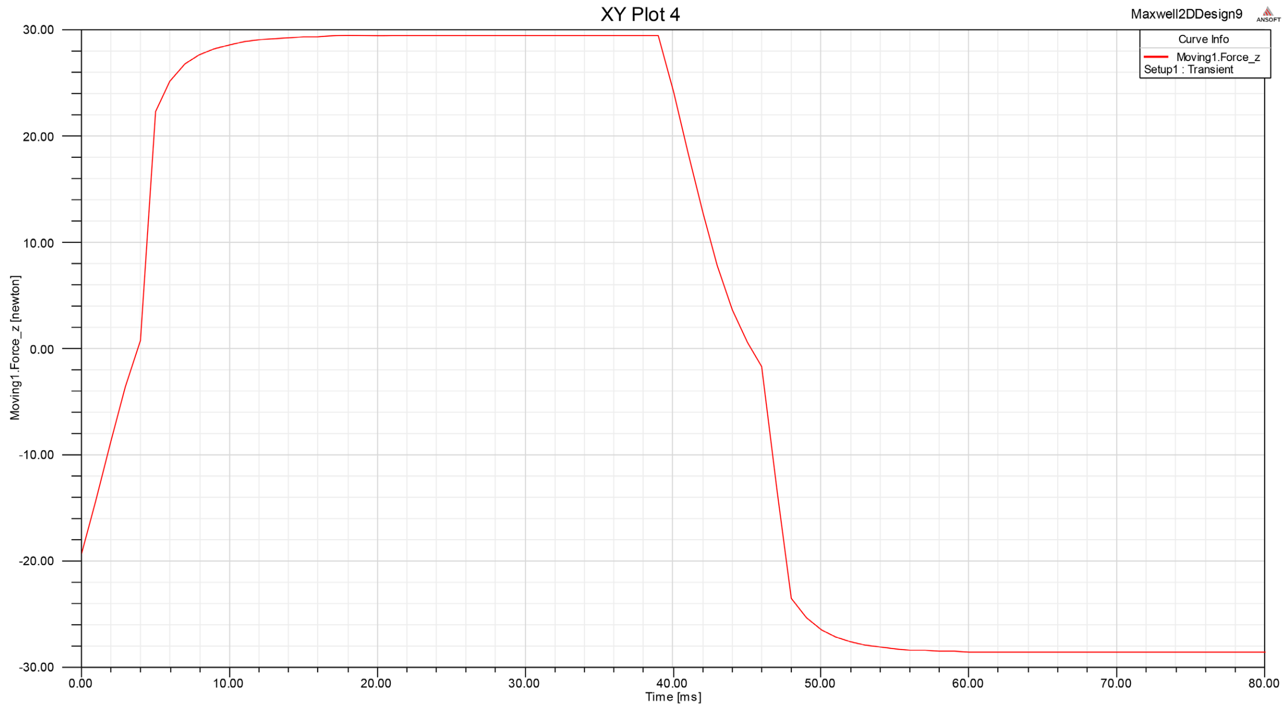

Figure 5. The resultant force curve of the armature during the switching process.

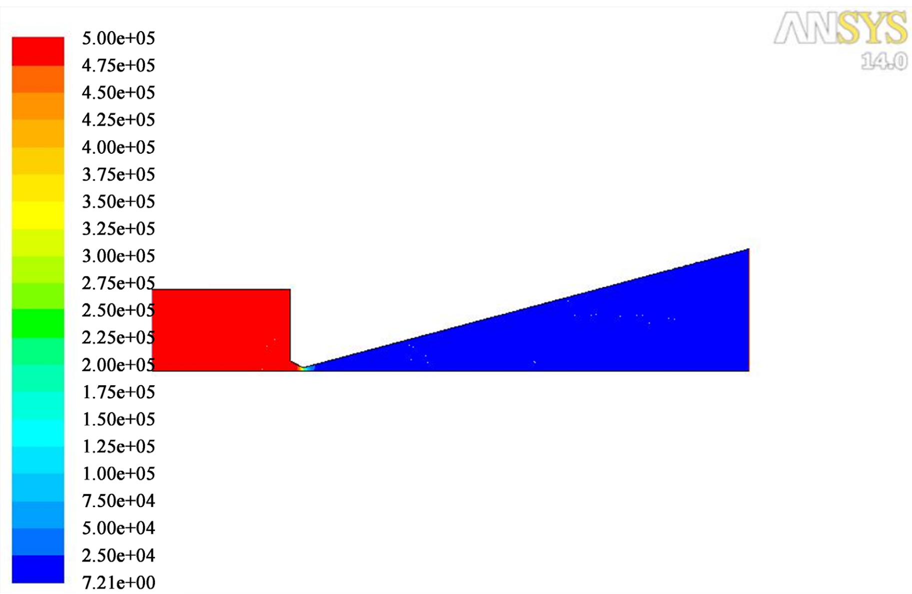

Figure 6. The pressure distribution of the Laval nozzle.

Table 1. Experimental result.

performance	design value	experimental result
thrust	40 mN × (1% ± 5%) (0.17 Mpa)	39.14 - 40.12 mN (0.17 Mpa)
Switching response time	Open: ≤20 ms	≤10 ms
	Close: ≤20 ms	≤10 ms

From the pressure and velocity distribution, we know that when the throat diameter is 0.47 mm, the requirement of the thrust of 40mN is met.

4. Experimental Study

By the thrust measurement device, we got real thrust of the thruster designed in this paper.

The experiment result is shown in Table 1, form the experimental study, it is shown that the long-life micro cold gas thruster developed in this paper meets the mission requirements.

5. Conclusions

We can get the conclusion as follows:

- As this micro-thrust should be continuous working more than 60 minutes, the traditional solenoid valve used for the thrusts can't complete the mission, because the latching valve can keep its position when it cuts off the outage, so we choose the latching valve as the thrust's control valve.
- From the structural strength simulation, we knew that the maximum principal stress on the valve body was 4.6 MPa, which was far less than the yield strength of the material of 400 MPa.
- According to the Latching Valve's Switching performance simulation and experimental results, we know that the switch reliability of the latching valve designed in this paper is sufficient, it can meet the operating conditions of the product in orbit.
- From the experimental results and compared with the numerical study, it shows that the long-life micro cold gas thruster developed in this paper meets the mission requirements.

Acknowledgements

This project is supported by National Natural Science Foundation of China. The authors thank the National Natural Science Foundation of China for the financial support.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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