# Experimental Study on the Influence of Magnetic Field on the Performance of Low-power Hall Thrusters

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**Abstract: With the development of small satellites, the low-power Hall thruster has received increasing attention with its unique advantages. In this paper, the experimental study of the low-power Hall thruster with variable conditions under two kinds of magnetic fields was carried out. The influence of the magnetic field on the volt-ampere characteristics of the low-power Hall thruster and the oscillation relationship between the hollow cathode and the Hall thruster were studied. The experimental results showed that at the same anode flow rate and anode current, the higher magnetic induction corresponds to a higher discharge voltage. What's more, as the anode current of the Hall thruster increases, the oscillation of the hollow cathode keeper current changes, and the anode current oscillation develops towards a higher frequency. The experimental results provide a certain reference for the design of low-power Hall thrusters.**

## I.Introduction

THE Hall Thruster is a kind of power device that provides thrust for spacecraft. It has the characteristics of large thrust power ratio, high specific impulse and long life. And it has a wide range of applications in spacecraft position maintenance, orbit transfer and attitude adjustment. In recent years, with the miniaturization of satellite platforms and the demand for tasks such as orbit transfer and attitude adjustment in the field of small satellites, the low-power Hall thruster will become more and more competitive in the field of electric propulsion with its advantages of large thrust power ratio, simple and reliable system.[1]

The Hall thruster relies on electromagnetic field to ionize and accelerate the working fluid to generate thrust.[2] The magnetic field has a critical influence on the performance of the Hall thruster. However, the miniaturization of the Hall thruster leads to large heat flux density and reduced performance of permanent magnet if the permanent magnet is used to generate magnetic field which is usually adopted especially in low-power Hall thrusters.[3] Although there have been many studies on the magnetic field,[4,5,6] more are about Hall thrusters with medium power and high power. Therefore, the influence of magnetic field on low-power Hall thrusters is still worth studying.

What's more, the oscillations in the Hall thrusters also have an impact on the performance.[7] So far, researchers have discovered a variety of oscillation forms[8] such as the low-frequency oscillation, the coupling oscillation[9] and so on, but more focused on the oscillation of the Hall thruster itself. There is less concern about the oscillation relationship and interaction between the Hall thruster and the hollow cathode during operation. The oscillation coupled with the hollow cathode may affects the normal operation and the lifespan of the thruster.

An experiment with variable conditions was conducted on a low-power Hall thruster designed by ourselves under different anode flow rates and two kinds of magnetic induction in this paper. The curves of volt-ampere characteristics

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were obtained. Meanwhile, the oscillation relationship between the Hall thruster and the hollow cathode was observed which is worth to be taken into consideration when designing a Hall thruster.

The structure of the paper is as follows: the experimental setup is presented in Chapter 2. In Chapter 3, the results will be presented and the conclusions drawn in Chapter 4.

## II.Experimental Setup

### A. Hall Thruster Experimental Prototype and Hollow Cathode

The experimental prototype we designed is a low power hall thruster, of which the operating power is on the order of 100W. The structure of this prototype is similar to traditional SPT type except for the magnetic field configuration.

The discharge channel is the main place where the physical process of the Hall thruster works. And the BN is usually chosen as the material because of its good high-frequency dielectric properties, machinability, heat resistance and thermal conductivity, and reasonable secondary electron emission coefficient. Our discharge channel made of BN has a mean diameter of 42mm and a height to diameter ratio of 0.8.

The magnetic field in the Hall thruster discharge channel is the key to maintaining the stability of the thruster and controlling the divergence of the beam. According to the general design criteria of the Hall thruster's magnetic field configuration,[2] the magnetic induction should be a positive gradient from the anode to the discharge channel exit, and the maximum value of magnetic induction should be located at the exit of the discharge channel. For low-power Hall thrusters, due to the small size of the structure, the use of coils to generate magnetic fields generates a lot of heat and takes up a lot of space, so in our design, two permanent annular magnets are used to generate magnetic fields. In our experiment, different magnetic fields were generated by replacing permanent magnets.

A hollow cathode is used as the electron source for Hall thrusters. In our experiment, the hollow cathode was placed perpendicular to the Hall thruster. The distance between the keeper hole and the axis of the Hall thruster was 5cm, and the distance from the exit plane of the discharge channel was 2cm. During the experiment, the working parameters of the hollow cathode were constant. The current of the keeper was 1.5A, and the flow rate was 6sccm.

The working fluid of Hall thruster and hollow cathode is Xenon.

### B. Vacuum Chamber

Hall thruster and hollow cathode were placed in the vacuum chamber which consists of two mechanical pumps, one roots pump and one oil diffusion pump. The cabin is made of stainless steel with a diameter of 1.8m and a length of 4m. When the experiment is operating, the vacuum degree can be maintained at an order of $10^{-3}$Pa.

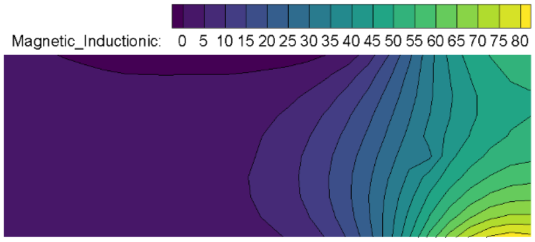
### C. Data Collection Equipment

Actual magnetic field configuration of the Hall thruster was measured by the Tesla meter with the help of the displacement mechanism. The probe of the Tesla meter is fixed on the displacement mechanism to measure different points in the discharge channel in a certain order. Then, the actual magnetic field structure of the discharge channel can be drawn by data points. The voltage and current of the keeper and the anode were monitored by the digital oscilloscope in real time.

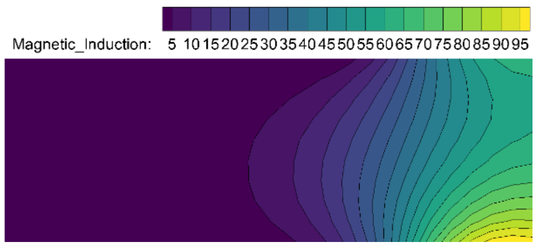
## III.Results

### A. Magnetic Field Configuration

Fig. 1 shows the radial configuration of the two magnetic fields in the experiment. It can be seen that both magnetic fields have a magnetic field configuration that is convex toward the anode. Fig. 2 shows the radial magnetic induction of the centerline of the discharge channel. It can be seen that both magnetic fields have a positive gradient and the maximum magnetic induction is approximately located at the exit of the discharge channel which is 526.4G for magnetic field configuration 1 and 625G for magnetic field for magnetic configuration 2.




a) Magnetic Field Configuration 1




b) Magnetic Field Configuration 2

**Figure 1. Magnetic Field Configuration**

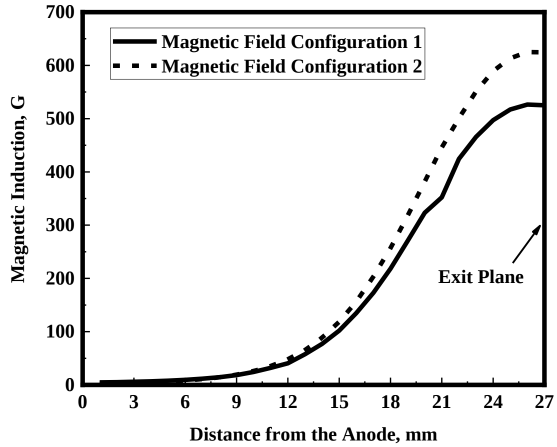



**Figure 2. Radial Magnetic Induction of the Centerline of the Discharge Channel**

### B. Relationship Between the Voltage and the Current of the Anode

Fig. 3 shows the relationship between the voltage and the current of the hall thruster anode at different magnetic field configuration and anode flow rates. Because of the power is low, the thruster operated in the mode that the current was constant. The flow rate of the anode which is controlled by the flow controller ranged from 4sccm to 12sccm. And at each anode flow rate, the current of the anode started to increase from 0.5A and the maximum is 1.4A. The solid line represents the magnetic field configuration 1 and the broken line represents the magnetic configuration 2. From the figure, we can learn that the voltage increases with the increase of anode current, and as the flow rate increases, the speed decreases. The magnetic field configuration has a certain influence on the performance of the hall thruster. As the figure shows, when the anode current is the same, the larger radial magnetic field corresponds to a higher anode voltage.

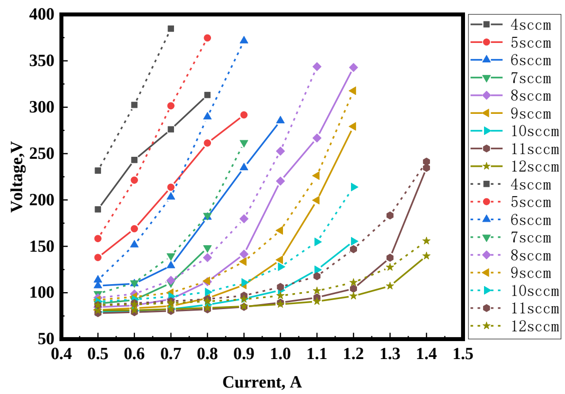
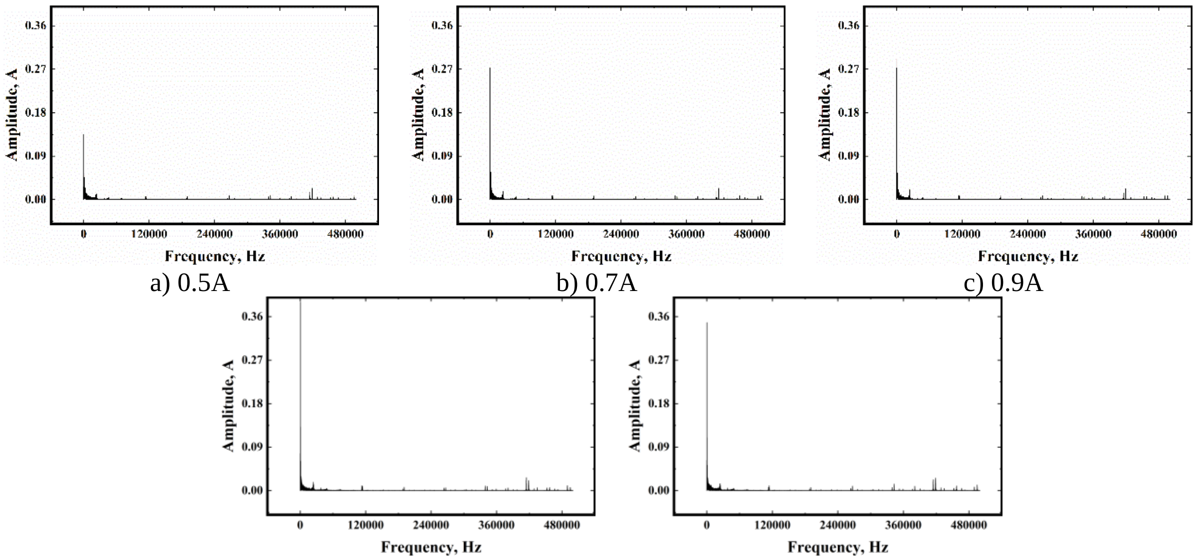



**Figure 3. Voltage-Current curves**

### C. Current Oscillation Relationship Between Hollow Cathode and Hall Thruster

We found an interesting phenomenon during the experiment. There is a coupled current oscillation between the anode and the hollow cathode in the process of increasing anode current.

In order to study this phenomenon, we first conducted a separate experiment on the hollow cathode. The metal plate was used as an anode and the cathode was operating at the condition that the current of the keeper was set to 1.5A and the flow rate was set to 6sccm (same as when the Hall thruster was operated). The current of the keeper was recorded as the anode current was changed from 0.5A to 1.4A. By performing the fast Fourier transform on the result of keeper current value cutting off its average value, the relationship between the amplitude and the frequency can be obtained, as shown in Fig. 4. It can be seen from the figure that when the anode current is 0.5A-1.2A, the amplitude tends to increase but the oscillation frequency is approximately the same.

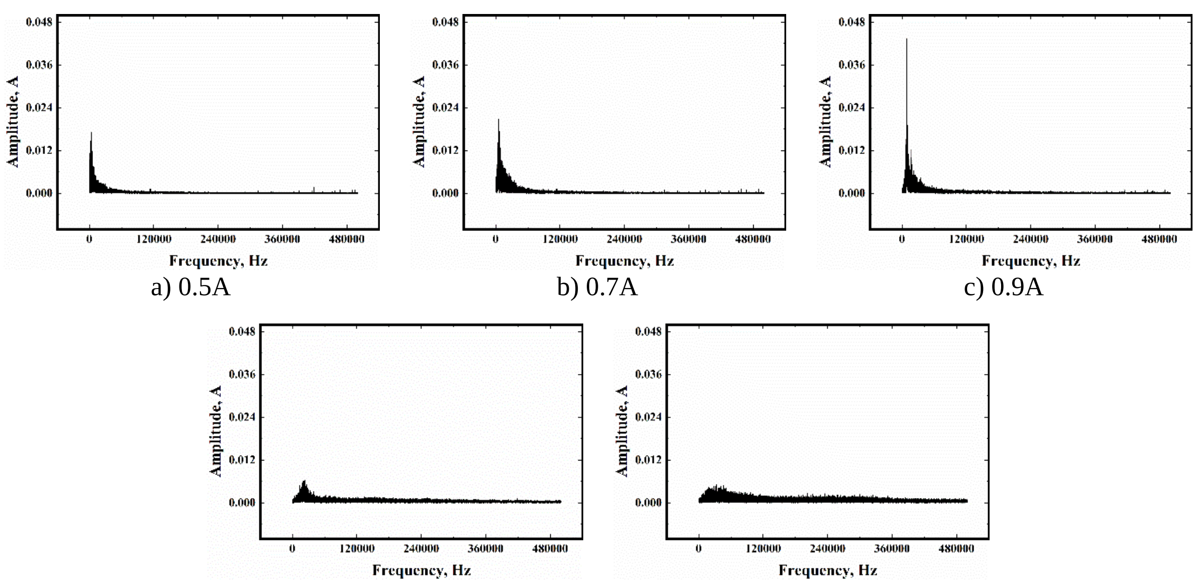



a) 0.5A b) 0.7A c) 0.9A

d) 1.1A e) 1.2A

**Figure 4. FFT Results for Plate Anode**

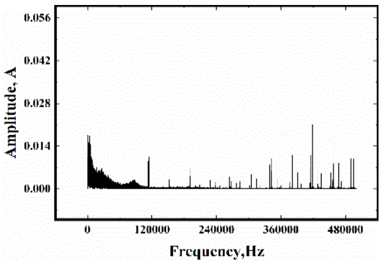
When the hollow cathode is operated in conjunction with the Hall thruster, the oscillation frequency changes when the anode current increases to a certain extent. Taking the operating condition that the flow rate of the Hall thruster is 9sccm as an example, Fig. 5 and Fig. 6 show the oscillation of the anode current and the keeper current under the magnetic field configuration 1, and Fig. 7 and Fig. 8 show the oscillation of the anode current and the keeper current under the magnetic field configuration 2. As can be seen from the figures, as the current of the anode increases, the amplitude increases, but the frequency is approximately the same, but when the current increases to a certain extent, the amplitude begins to decrease and the frequency expands toward a higher direction. At the same time, the oscillation of the current of the keeper is also change.



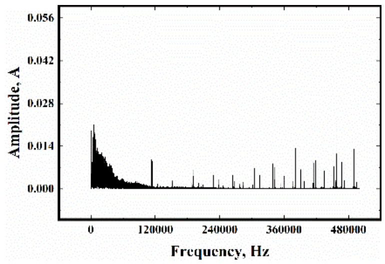

a) 0.5A b) 0.7A c) 0.9A

d) 1.1A e) 1.2A

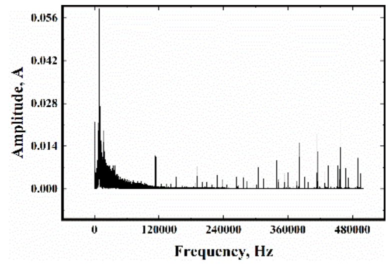
**Figure 5. FFT Results of Anode Current for Magnetic Field Configuration 1**



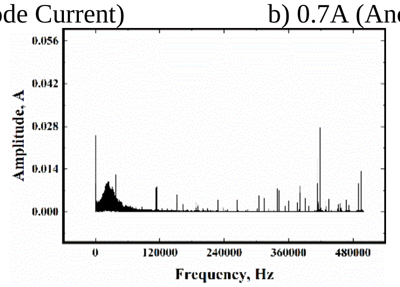
a) 0.5A (Anode Current)



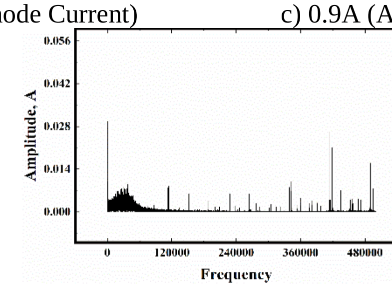
b) 0.7A (Anode Current)



c) 0.9A (Anode Current)

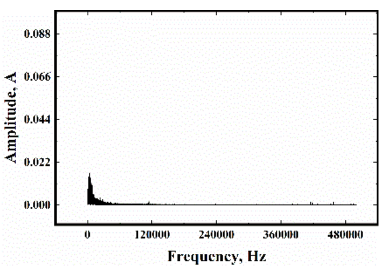


d) 1.1A (Anode Current)

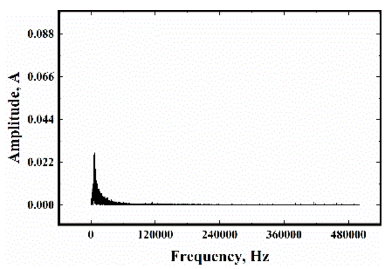


e) 1.2A (Anode Current)

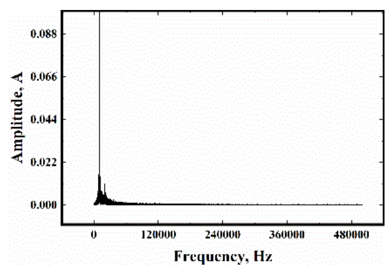
**Figure 6. FFT Results of Keeper Current for Magnetic Field Configuration 1**



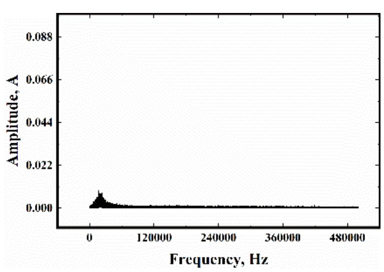
a) 0.5A



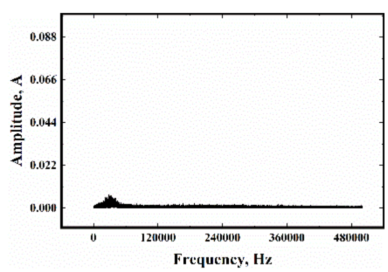
b) 0.7A



c) 0.9A

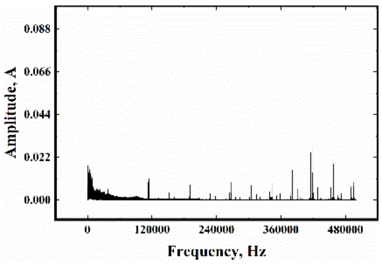


d) 1.1A

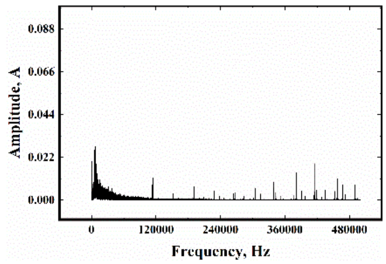


e) 1.2A

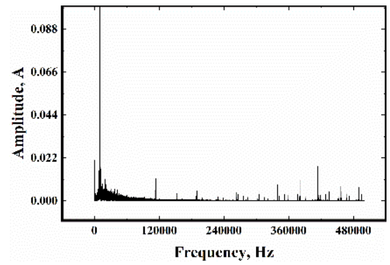
**Figure 7. FFT Results of Anode Current for Magnetic Field Configuration 2**



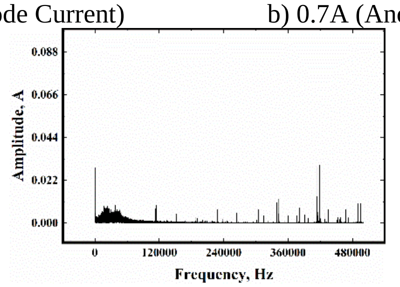

a) 0.5A (Anode Current)



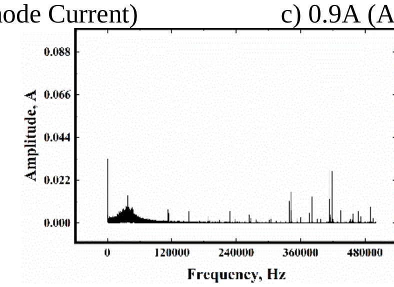

b) 0.7A (Anode Current)




c) 0.9A (Anode Current)




d) 1.1A (Anode Current)




e) 1.2A (Anode Current)

**Figure 8. FFT Results of Keeper Current for Magnetic Field Configuration 2**

In summary, we can conclude that when the anode current becomes larger and the anode voltage rises as the Hall thruster is running, the oscillation of the hollow cathode and the Hall thruster anode can be coupled, which is worth to be taken into consideration when designing a Hall thruster.

## IV.Conclusion

A variable working condition experiment was performed on a Hall thruster under two kinds of magnetic field configuration. The maximum values of the magnetic induction at the center line of the discharge channel are 526.4G and 625G respectively. The results showed that the rate at which the voltage rises with the current slows as the flow rate of Xenon increases. While at the same flow rate of the Xenon for thruster and the current of anode, higher magnetic field strength corresponding to higher anode voltage.

During the experiment, an important phenomenon is that when the current of Hall thruster increase, the oscillation of the hollow cathode and the Hall thruster anode can be coupled. The oscillation frequency of the thruster develops to higher level with the amplitude of oscillation decreases and the oscillation mode of the hollow cathode also changes. We hold the view that this phenomenon should be taken into consideration when designing a hall thruster. So, it is our later work to continue to study the causes of this oscillation relationship coupled with the hollow cathode.

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