The Discharge Process and Experimental Test of the 6.5kW Hybrid Engine

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Abstract: The AGI-Engine integrating with another electric propulsion thruster technology, mounted concentrically around the exterior of a Hall Effect Thruster (HET), is Dual-Mode Hybrid-Engine (DMH-Engine). For the DMH-Engine, it could have two manifestations: a ‘matched-mode’ where both the AGI-Engine and alternate electric propulsion thruster technology are sized to operate at comparable power levels, which each providing primary functions; and a ‘mixed-mode’ where AGI-Engine is a much lower power device, providing an on-station high-Isp capability to complete a high power electric propulsion thruster used for primary propulsion. In 2015 Lanzhou Institute of Physics (LIP) developed a 6.5kW DMH-Engine, which is composed of 5kW AGI-Engine and 1.5kW Hall thruster. In 2016, LIP completed the performance tests of the AGI-Engine, Hall thruster and DMH-Engine. The experimental results showed that the AGI-Engine and Hall thruster could be operated normally and successfully. However, because of the problem of PPU and the equipments, the DMH-Engine only completed the ignition tests. This paper introduces the 6.5kW DMH-Engine’s constitution, mechanism, the simulation results and the experimental results of AGI-Engine and Hall thruster.

Key words: DMH-Engine, AGI-Engine, Hall thruster

1 Introduction

Because of its high thrust, large specific impulse, high efficiency and long lifetime, electric propulsion[1] has been used to perform different space missions, such as orbit transfer, position maintain and deep space exploration. By using ion electric propulsion system on spacecraft, satellite’s effective payload mass can be reduced, thruster’s lifetime can be extended and the launching costs can be reduced.

However, the maximum power of ion thruster is only 50kW, which means it needs at least 20 ion thrusters to work together to make a 1MW electric propulsion system achieve its designed performance. This actually is very difficult to complete. Therefore, enhancing the power of the ion thruster becomes urgent.

In 2012, NASA Glenn Research Center analyzed the advantages to develop the Next-Generation of Electric Propulsion Thrusters (NGEPT) from which a truly-term (3-5 year development) high-power (10kW to >300kW) high performance technology that could meet the need of the applicable requirement of Defense Advanced Research Projects Agency (DARPA). To better understand the DARPA solicitation the Patterson

M J rewrote it into a series of requirements. In summary, the solicitation demands the development of an advanced electric propulsion thruster with performance characteristics-primarily thrust-to-power ratio---well beyond SOA[2-7]. Once the requirements were documents it was necessary to determine whether or not they are theoretically feasible. The analyzed results showed that it was reasonable and feasible. The DMH-Engine could be operated in multiple modes: Hall-effect mode, ion mode and burst mode. It could be applied to any application for which the high thrust-to-power characteristics of a Hall-Effect thruster and high specific impulse capability of an ion thruster would be advantageous. Then the paper proposed a next-generation electric propulsion thruster design concept, which is Dual-Mode Hybrid Engine (DMH-Engine).

The DMH-Engine is the combination of Hall-Effect thruster and Ion thruster. It is a thruster with an annular-shaped discharge chamber and annular-shaped ion optics which are then mounted circumferentially around the exterior of a conventional central Hall-effect thruster, with a centrally-positioned neutralizer cathode assembly common to both the Ion and Hall plasma sources.

The ion thruster used in DMH-Engine is called Annular-Geometry ion engine (AGI-Engine), which consists of the annular discharge chamber and annular ion optics, configured with a centrally-mounted neutralizer cathode assembly. Compared with the conventional ion thruster, the AGI-Engine could obtain better performance by achieving high perveance with sub-mm critical dimensions in inter-electrode gap, electrode thicknesses and electrode apertures.

In China, Lanzhou Institute of Physics(LIP) began to investigate the mechanism of DMH-Engine and firstly develop a 6.5kW DMH-Engine in 2015. The thrust, specific impulse and efficiency of the 6.5kW DMH-Engine are 80-210mN, 1500-5000s and ⩾60% respectively. The DMH-Engine is composed of 5kW AGI-Engine and 1.5kW Hall thruster. Different from the thruster developed by GRC, 5kW AGI-Engine firstly used the double hollow cathodes geometry and Mo flat annular electrodes, which could greatly improve the plasma uniformity and reduce the divergence angle. In 2016, the AGI-Engine and DMH-Engine completed the performance tests. The experimental results showed that the AGI-Engine and Hall thruster could be operated normally, respectively and they all achieved their designed performance. However, because of the PPU and equipment, the DMH-Engine only completed the ignition and did not test its performance.

This paper will introduce the 6.5kW DMH-Engine's constitute, mechanism, the simulation results and the experimental results of AGI-Engine and Hall thruster. The paper is organized as follows. In Section 2, the consistent and mechanism of DMH-Engine are presented. Section 3 gives the numerical model and simulation method of discharge chamber. Section 4 discusses the simulation and experimental results. Finally, a brief conclusion is given in Section 5.

2 6.5kW DMH-Engine

The 6.5kW DMH-Engine consists of 5kW AGI-Engine and 1.5kW Hall thruster. Its inner discharge channel is Hall thruster and outer one is AGI-Engine and a neutralizer cathode is centrally positioned. The neutralizer cathode will considered as the electrons sources for ionizing and neutralizing.

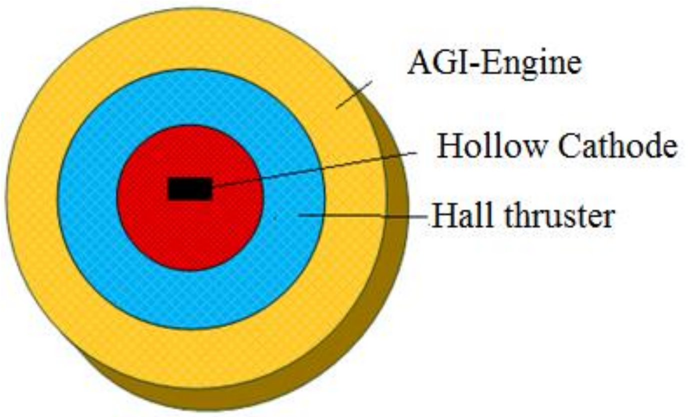


Fig.1 6.5kW DMH-Engine

The mechanism of the DMH-Engine is as follows:

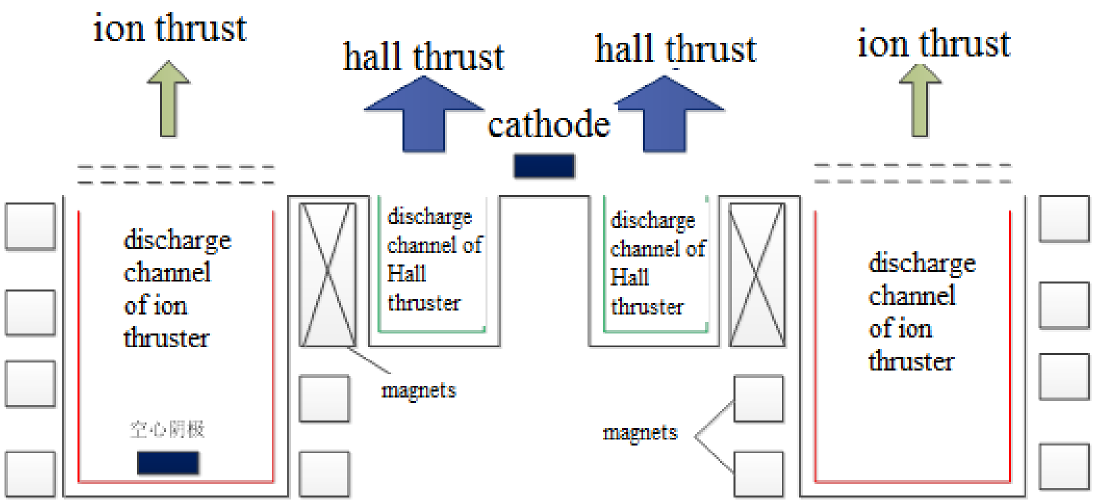


Fig.2 mechanism of DMH-Engine

The Hall thruster inside of the DMH-Engine will be designed according to the LHT-100 Hall thruster which is developed by Lanzhou Institute of Physics completely, including its discharge chamber, magnetic field topography, magnetic field strength and gas distribution.

The outside discharge channel of DMH-Engine is AGI-Engine. Its magnetic field topography of discharge chamber is ring-cusp. The thruster uses the double flat ion optics to improve the uniformity of the beam ions and reduces the angle of the beam current.

Hollow and neutralizer cathode is LaB6 hollow cathode.

3 Simulation model

As DMH-Engine discharge chamber has a cylindrical axisymmetric structure, the problem of this study belongs to a two-dimensional cylindrical coordinate's axisymmetric problem; therefore, we choose half of it as the object of this study. The 2-D calculation is shown in Fig.2. This computational domain of AGI-Engine includes the discharge chamber, the hollow cathode, the discharge wall(anode), the screen grid, and the magnets. The Hall thruster includes the discharge chamber, the hollow cathode, the magnets and the discharge wall.

The boundary conditions of AGI-Engine is as follows: the anode surface in the chamber and the potential is Vdi. The hollow cathode is in the inside of the chamber where the electron emission starts and the potential is Vci. The potential of screen grid is marked by Vs. The static magnetic field inside the discharge chamber is created by the magnets. These magnets labeled by 1, 2, 3 and 4 are located on the outside surface of the discharge chamber walls.

The boundary conditions of Hall thruster is as follows: the potential of anode surface and hollow cathode are Vdh and Vch. The static magnetic field is produced by magnets 5 and 7.

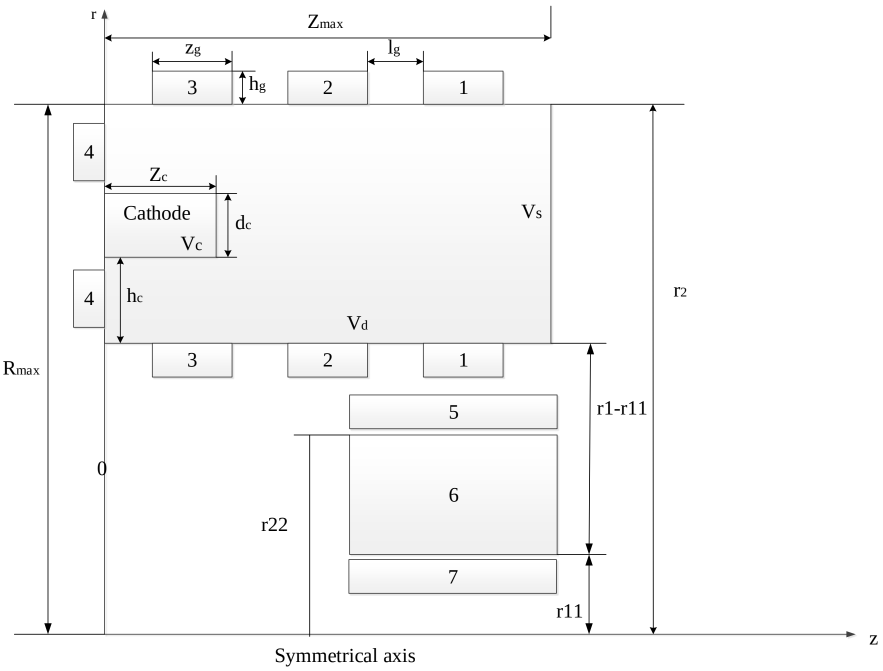


Fig.2 A schematic of the computational domain

Zmax and Rmax are the maximum axial and radial position of the computational domain. The inner and outer radiuses of the AGI-Engine discharge chamber are indicated by r1 and r2, respectively. The size of Hall thruster's discharge chamber is labeled as r11 and r22. zc, dc and hc represent the thickness, diameter of the cathode and the distance from the cathode to the symmetry line. The length, thickness and the distance between two magnets are zg, hg and lg.

4 Discussion

4.1 DMH-Engine

Fig.3 shows the 3-D simulation model.

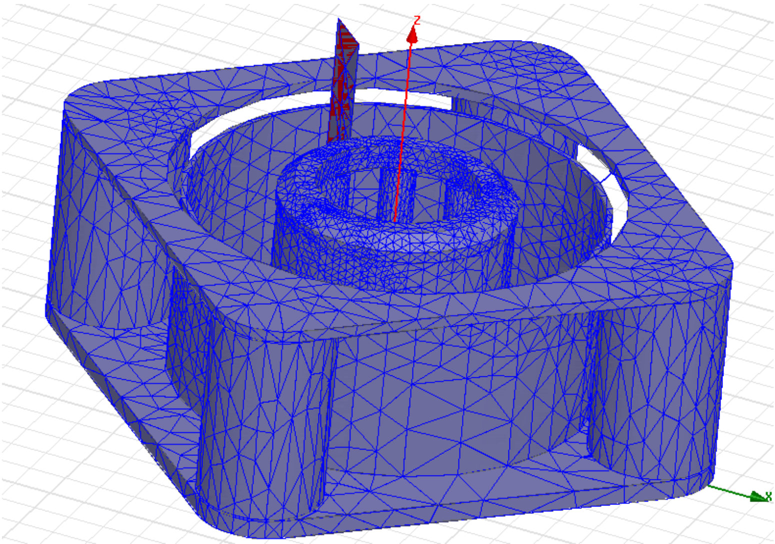
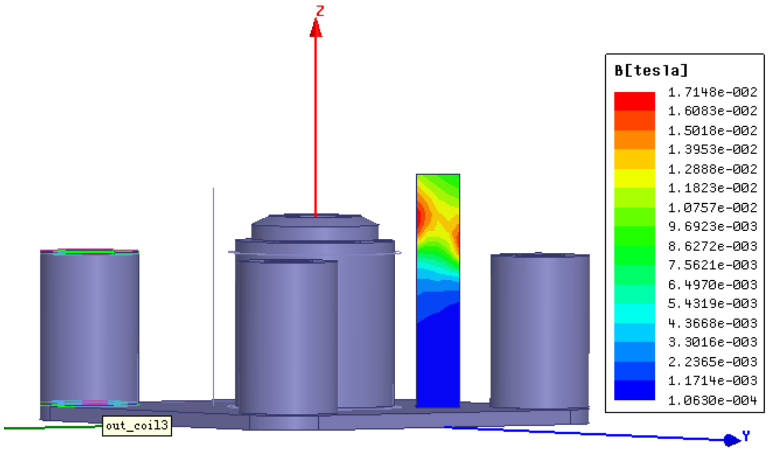
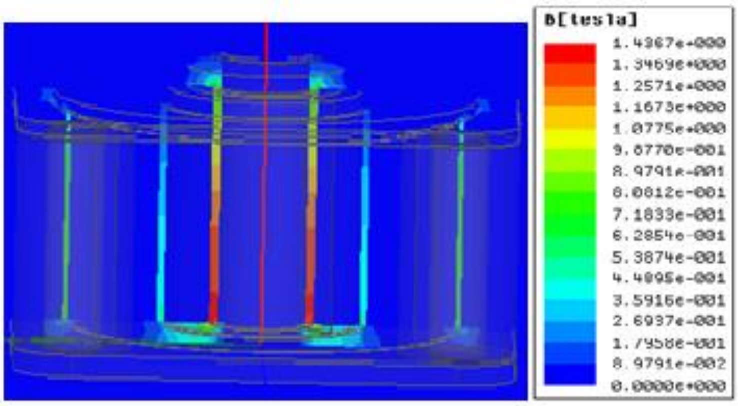


Fig.3 3-D simulation model

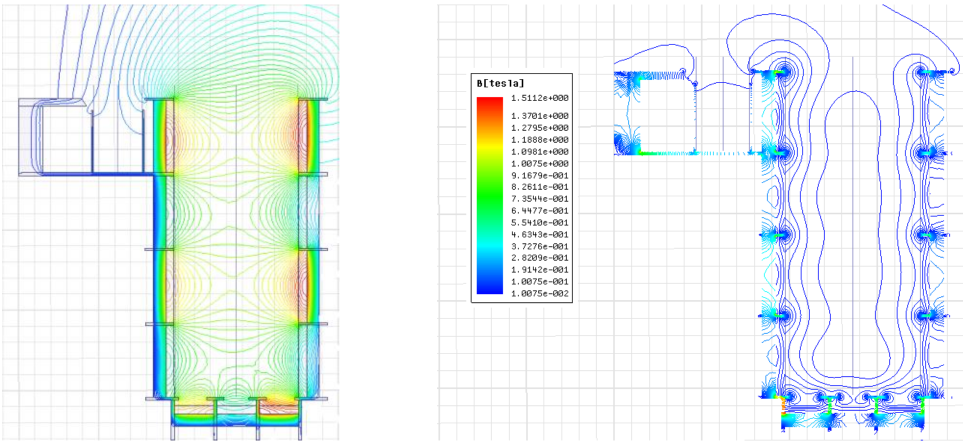
Fig.4 shows the magnetic field strength of discharge channel of DMH-Engine.



(a) magnetic field



(b) magnetic field strength



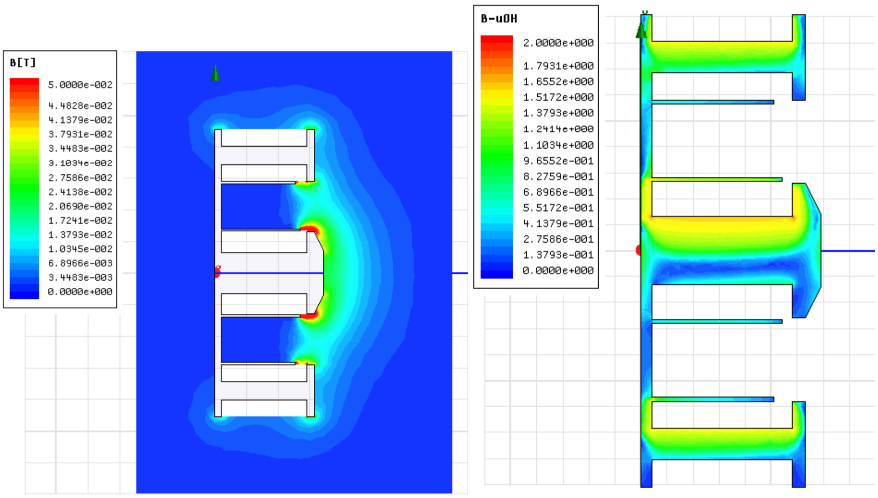
(c) magnetic field (d) strength

Fig.4 magnetic field strength of discharge channel of DMH-Engine

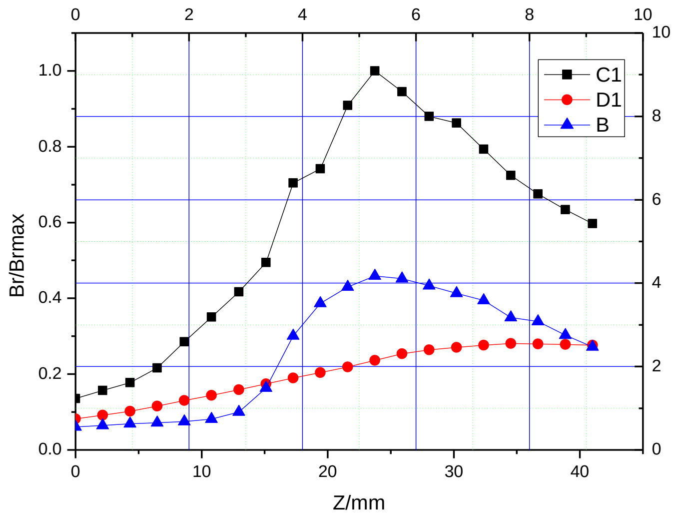
The results show that the maximum magnetic field strength of the DMH-Engine is 1.49T, which locates at the connection of the inner string and the baseboard. The material used is DT-4C, the current magnetic field is 2.15. The results need the requirement of the magnetic field of DMH-Engine.

4.2 Hall thruster

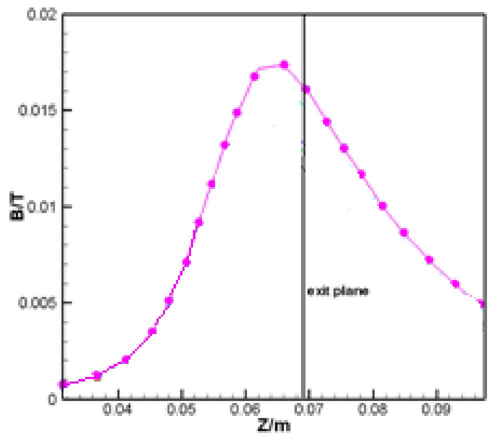
Fig.5 shows the magnetic field results of Hall thruster.

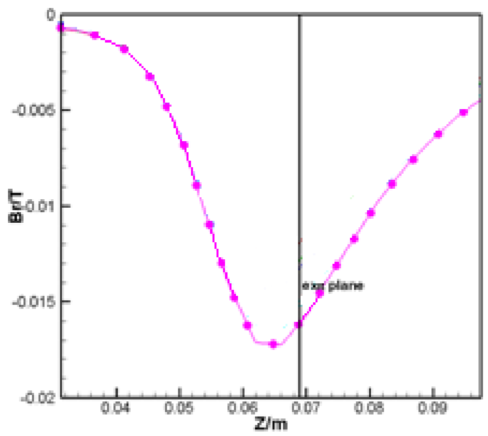


(a) magnetic field strength

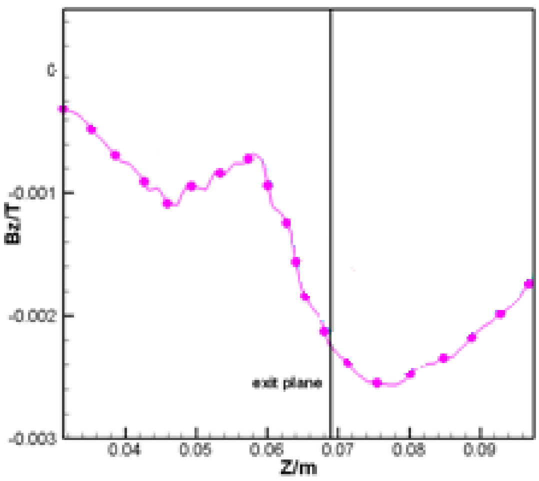


(b) magnetic field strength of discharge channel and downstream region
Fig.5 Hall thruster





(a) magnetic field B (b) radial magnetic field strength Br



(c) axial magnetic field strength Bz
Fig. 6 simulation results

The results show that the magnetic field has an axisymmetric structure, the magnetic field of the exit of the discharge channel is perpendicular to the axis of the thruster, where the maximum magnetic field strength locates. At the vicinity of the anode surface, the magnet field strength is so small and hardly affect the motion of the plasma. In the discharge chamber of the Hall thruster, the magnetic field mainly confines the electrons comes from the thruster's exit.

4.3 AGI-Engine

Fig.6 shows the computational domain of the AGI-Engine.

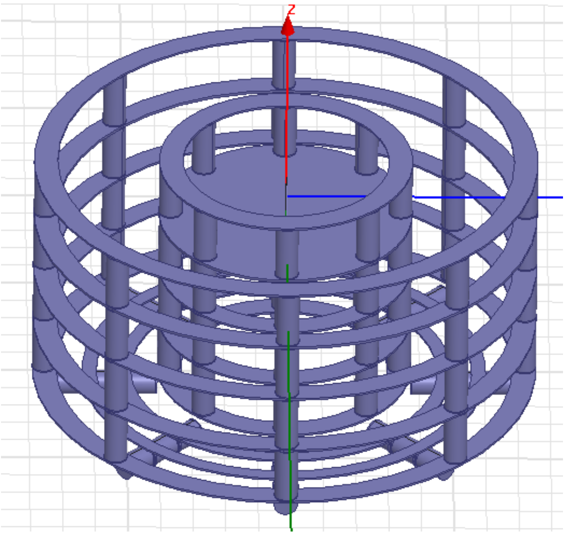
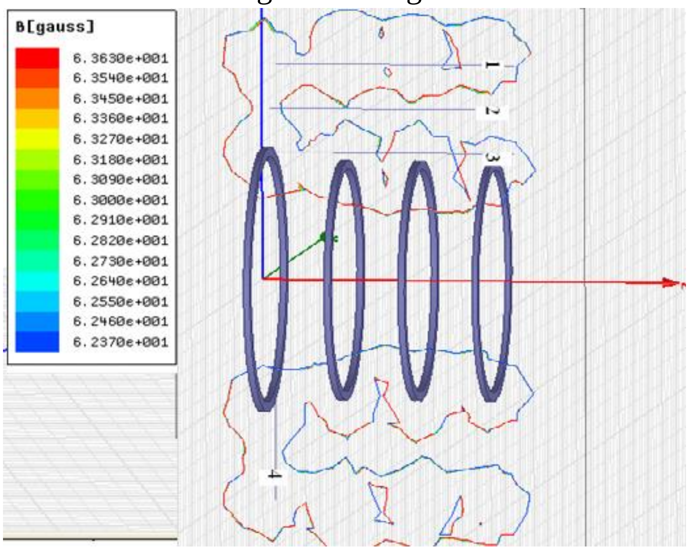
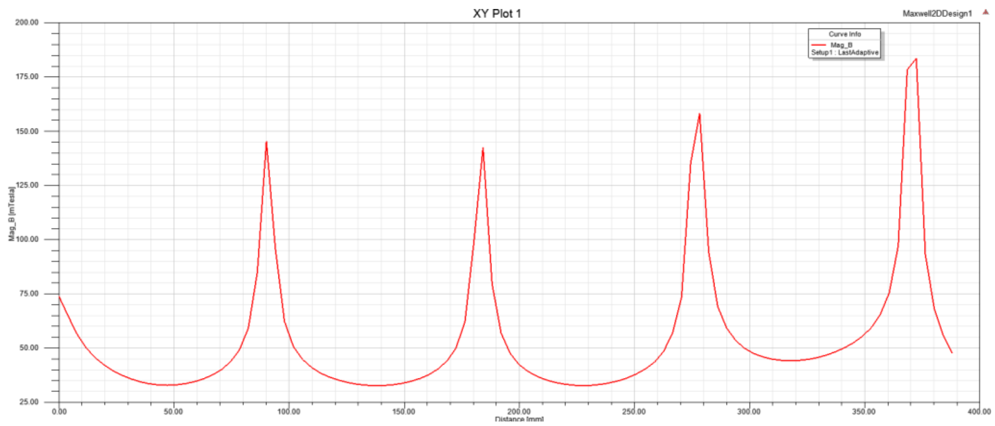


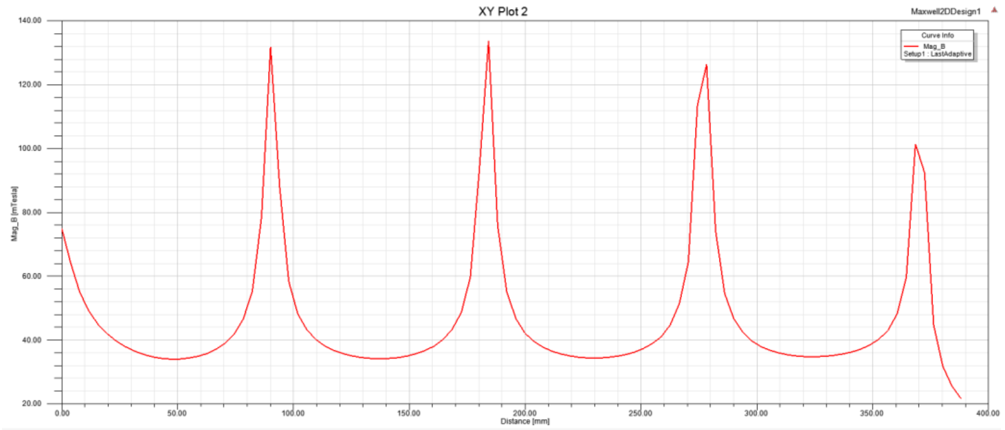
Fig.6 AGI-Engine



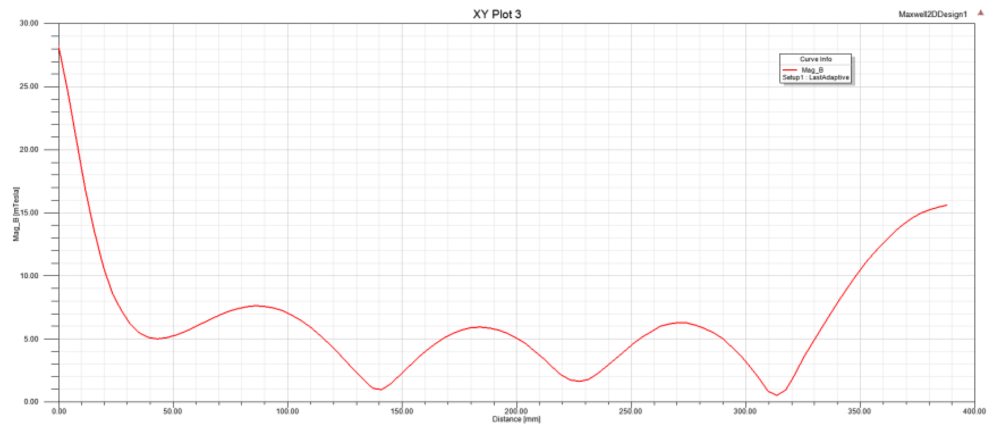
(a) magnetic field



(b) inner anode surface of the discharge channel



(b) outer anode surface of the discharge channel



(b) center anode surface of the discharge channel

Fig.6 AGI-Engine

The results show that the inner and outer anode surface of the discharge channel has a better asymmetry. The magnetic field strength of the inner anode surface is higher than outer one and the center strength is lower than the other regions.

4.4 Experimental results

The schematic of the TS-6 vacuum chamber of DMH-Engine's performance test is shown in Fig.7. The test equipment is composed of the vacuum pumping system, gas supply system and power supply controller. The limited pressure of the TS-6 vacuum system is 7.0×10^{-4}Pa, while the operating pressure is less than 6.7×10^{-3}Pa.

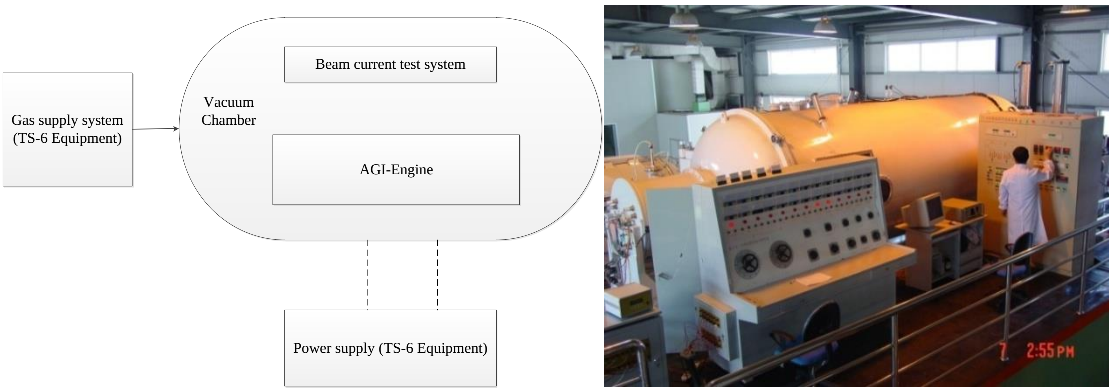


Fig.7 The schematic of the TS-6 vacuum chamber

Fig.8 shows the experimental test results for initial ignition.

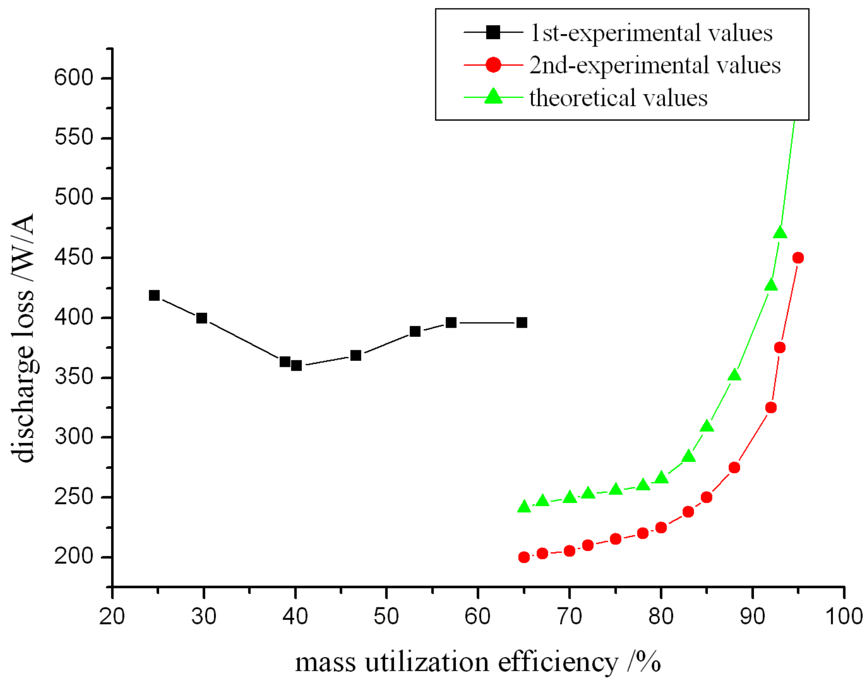


Fig.8 experimental tests

The results show that, the ionization in the discharge chamber is not enough to extract amounts of ions to form beam current. The maximum mass utilization efficiency and the discharge loss are only 64.83% and 418.32W/A, respectively. It is analyzed that the magnetic field could not confine the electrons completely, which makes most of them be absorbed before collision. However, after the optimization of magnetic field, the mass utilization is 89.16% and its corresponding the discharge loss is 308.6W/A. The result shows that the performance of discharge chamber improves notably.

5 Conclusion

The constitution, the mechanism, simulation model and simulation results of the DMH-Engine are presented in this paper. It also gives the experimental results of the AGI-Engine and Hall thruster. The experimental results show that the AGI-Engine and Hall thruster could be operated normally and successfully. Although the DMH-Engine was not be tested its performance, the simulation and ignition results show that it could also be operated successfully. LIP plans to carry out the performance experiments in recent months.

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