Plasma and Electrode Emissions from a 1 kW Hydrogen-Nitrogen Arcjet Thruster

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INTRODUCTION

The use of arcjets for satellite propulsion has expanded the operating realm of these devices and has increased the desire for better understanding of the physical basics in the process [1]. There are several key factors that affect the performance of arc discharges in an arcjet thruster, among which the arc-electrode interaction and electrode erosion are important. These features closely affect the energy conversion efficiency and the life time of the thruster. In arcjet thrusters, the measurement of electrode temperatures and the study of arc attachment are often difficult due to the fact that these electrode surfaces are seemingly inaccessible, and that the plasma arc itself is a likely source of optical interference. Using specially designed anode/nozzle, the arc root behavior under steady working condition was studied [1, 2]. However, the dynamic development of the arc root attachment from the time of ignition to the stably working condition is of great interest, as failure analysis show that most electrode erosion occur in the arcjet ignition process [3]. And it is also important to study the arc root behavior without changing the nozzle structure. In this study, dynamic optical access of the plasma and electrode emissions from a 1 kW hydrogen-nitrogen arcjet thruster has been carried out.

EXPERIMENTAL DETAILS

Based on previous experimental scheme in studying arc root behavior in a specially designed non-transferred dc plasma torch operated at reduced pressure [4], continuous monitoring of the images inside the thruster nozzle was done by a high-speed-video camera (HSVC). Fig. 1 shows the schematic illustration of the experimental setup. The 1 kW class arcjet thruster was positioned in a Φ2 m × L4 m vacuum chamber. The nozzle of the arcjet thruster was regeneratively cooled with a throat diameter of 0.7 mm and an exit diameter of 12 mm. The nozzle temperature was measured by two infrared pyrometers with a combined measuring range of 200 – 2000 ℃. A 45º tilted copper mirror was used to reflect the end-on view of the nozzle to the outer HSVC. The HSVC (16 μm/pixel, 512 × 512 pixel areal) was coupled to a telephoto lens with focal length of 200 mm. Interference filters with wavelengths of 700 nm and 460 nm were used to isolate the desired thermal emission or plasma emission signals from other perturbations. Reference [5] shows that for wavelengths greater than 700 nm, the intensity of axial emission is dominated by thermal emission and there is little or no interference from the luminous plasma. Therefore, the 700 nm filter was used for inside nozzle temperature monitoring. In order to better distinguish the ionized region from thermal emission and cathode emission, a 460 nm, 10 nm bandwidth interference filter was mounted before the telephoto lens to obtain the nitrogen ion lines, such that the images obtained can reveal the distribution of nitrogen ions. Since the 460 nm filter allows only the nitrogen ion lines to pass through, it helps to determine the arc root area. The filtered signal was then detected by a high-speed video camera. In the present study, the camera speed and exposure time were chosen such that the intensity of the images will not saturate. Intensity calibration was performed before the experiment with a tungsten filament lamp, whose temperature is known for a given range of input currents. The obtained kinetic series of images were then analyzed by the software of ImageJ (National Institute of Health. USA), from which dynamic inside nozzle temperature distributions, current density distributions and the development of arc root attachment types, motions and positions in the nozzle of 1 kW class H_2-N_2 arcjet thrusters were studied. Nitrogen-hydrogen mixture with volume ration of 1:2 was fed into the arcjet as the propellant. The total mass flow rate was 35 mg/s and the input power ranged from 300 – 900 W.

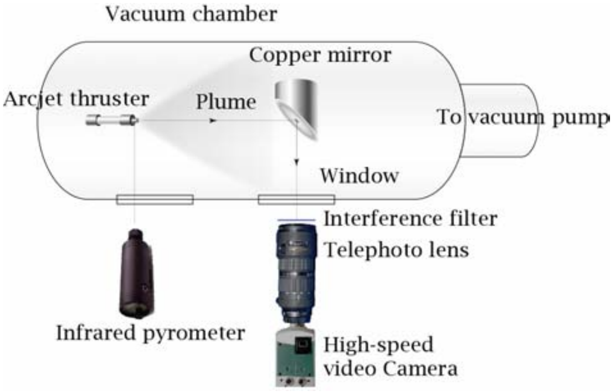

Figure 1. Schematic diagram of the experimental system.

RESULTS AND DISCUSSION

Figure 2 shows the time dependent nozzle outside temperature history. With an input current of 8 A (input power of about 770 W), the nozzle temperature increases to 1500 ℃, 4 minutes after the ignition. Kinetic series of images taken by the high-speed video camera show that at the ignition stage, asymmetric and constricted type arc root attachment is seen. The attachment point moves randomly on the nozzle surface. Most of the time, it moves in the region upstream of the throat and cannot be seen. Fig. 3 A1 – B10 show 20 continuous images taken at the ignition stage, from which an unstable arc root attachment can be confirmed.

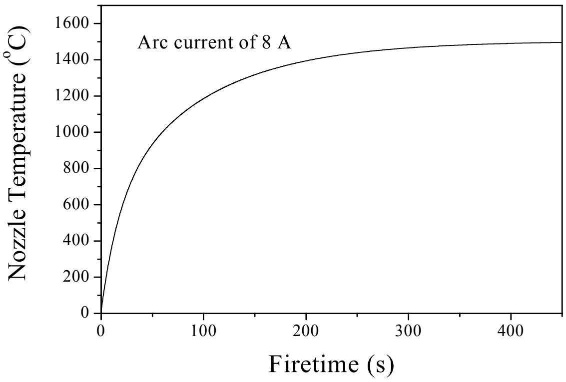

Figure 2. Change of nozzle temperature with time.

As the nozzle temperature increases, the anodic arc root moves out to the expansion cavity and a symmetric, diffused type attachment is observed. At this time, the arc root is stable, and no obvious fluctuation in continuous images can be seen (Fig. 3 C1 – F10).

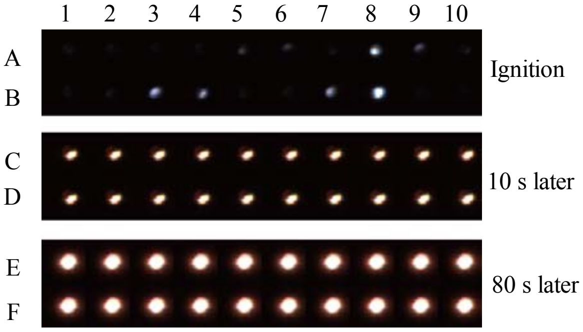

Figure 3. Kinetic series of images taken at different operating stage of the arcjet thruster. A1 – B10: during the ignition; C1 – D10: 10 s after ignition; E1 – F10: 80 s after the ignition.

Previous research [6] of the arc root behavior in a water-cooled dc plasma torch showed that the addition of hydrogen or nitrogen in small volume of several percent changed the arc root from diffused to constricted in argon plasma. However, for the arcjet thruster with hot anode, diffused type arc root attachment was observed for the H_2-N_2 plasma. Fig. 4 (a) shows the result. At stably working condition, the addition of hydrogen promotes the diffused type arc root attachment. Larger area of arc root attachment is seen, which also corresponds to the higher arc voltage when hydrogen is added. Radial line profiles across the center of the nozzle are shown in Fig. 4 (b).

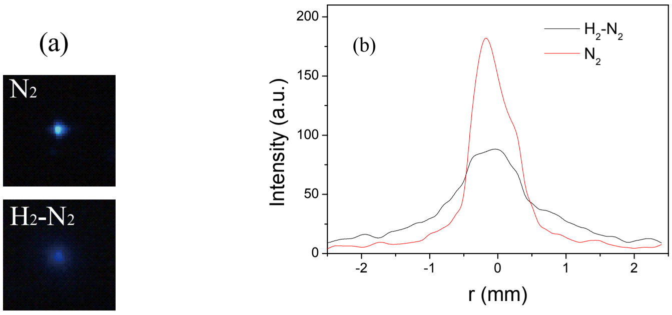

Figure 4. Nitrogen ion distributions in the nozzle with or without hydrogen addition. (a) images taken at stably working condition and (b) radial line profiles of the detected intensity.

With pure nitrogen as propellant, the anodic arc root attaches near the throat exit with an attachment diameter of about 1.0 mm. With the addition of hydrogen, much wider attachment is seen clearly with the diameter of about 2.2 mm. Taking in the throat diameter of 0.7 mm and the divergence angle of 15º, such an increase of the attachment diameter leads to a downstream attachment position of 1.2 mm.

These results show that nozzle temperature plays an important role in affecting the arc root attachment mode. Higher nozzle temperature promotes diffused type attachment while constricted type attachment occurs at lower nozzle temperatures.

In an arcjet thruster, high current density over 108 A/m2 in a constricted arc root attachment may lead to severe anode erosion and affect the long-term performance of the thruster. Above results hint that through the optimization of plasma generation parameters the nozzle structure, it is possible to achieve diffused type arc root attachment with relatively high arc voltage and low current density. Such combination may improve the stability of the arcjet thruster and promote its lifetime.

The details of the inside nozzel temperature distributions and current density distributions obtained by using the 700 nm filter will be discussed in the conference.

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