Alternative Neutralization Technique for a 40 Watt Quad Confinement Thruster

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This study investigates the use of an Inertial Electrostatic Confinement (IEC) device as a neutralization method for a low power (40 W) variant of the Quad Confinement Thruster. This paper presents the outcomes of recent experiments to characterize the current and voltage behaviour of this device. The device the was operated on both krypton and carbon dioxide. A maximum neutraliser current of 40 mA was produced at a voltage of 1 kV, while operating across a carbon dioxide propellant flow range of 1.25–5 mg/s and a maximum current of 30 mA was possible at a voltage of 1–1.8 kV while operating using krypton as propellant over a mass flow range of 1.85–4 mg/s.

I. Introduction

One of the key challenges in the application of Gridded Ion or Hall-effect type propulsion devices for very low levels of power (below 50 W) is the power and propellant demands of conventional beam neutralizers. Typically this role is fulfilled by the well-known Hollow Cathode. Even for a Hollow Cathode designed to operate at low sustaining currents,[1] the power (typically $\ll$25 W) and propellant flow (typically $\ll$0.08 mg/s) can significantly decrease the overall specific impulse and thrust efficiency of these low power devices. For such low power applications, a novel method of neutralizing the outgoing ion beam with a lower power and lower propellant usage would be highly desirable.

Inertial electrostatic confinement devices have been shown[3] to produce plasmas can be sustained at low input powers of below 5 W while producing a population of electrons which are typically considered to form a virtual cathode within the centre of the IEC device. In the present study an IEC-based neutraliser has been designed around a low power Quad Confinement thruster.[2] In addition to the low power profile, the secondary benefit of this neutralization strategy is that it's not reliant on a dedicated propellant supply. The background pressure needed to maintain a stable IEC discharge is provided by the anode flow alone. A schematic of the thruster is shown in Fig. 2.

A negatively charged cylindrical grid (neutralizer) and grounded cylindrical electrode (ground return) surround the channel exit downstream of the region of ion acceleration. The neutralizer grid sustains a low density inertially confined plasma downstream of the channel exit, which acts as a virtual cathode for the main discharge. The electron current needed to neutralize the outgoing ion beam is balanced by the ion loss rate to the ground return electrode. Previous experimental investigations of this device have shown that a stable discharge can be sustained with less than 5 W supplied to the IEC stage.

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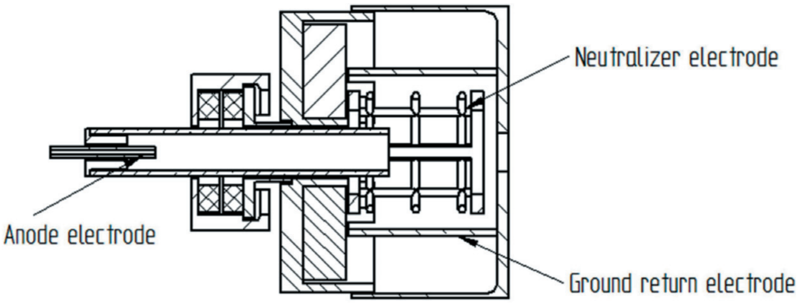


Figure 1: Schematic view of the QCT-40. The three electrodes are labelled. The anode electrode is connected to a low voltage high current power supply and the neutralizer electrode was connected to a high voltage low current power supply. Both supplies were connected to the common ground return electrode.

In order to realise this concept as an alternative neutraliser for a thruster, the characteristics of the anode and neutraliser discharges must be explored. In particular the maximum anode and neutraliser power levels that can be supported by the thruster and the current/voltage characteristics.

Since the thruster does not rely upon the use of a chemically sensitive electron emitting material, such as lanthanum hexaboride, operation using alternative propellants should be possible. Thus, the aim of this investigation was to explore operation of the device for high neutraliser powers and to investigate differences in behaviour between operating using krypton and carbon dioxide propellants.

II. Experimental Arrangement

The QCT-40 was connected according to the schematic in Fig. 2. For the purpose of these experiments and in readiness for future experiments, the thruster was mounted on a pendulum thrust balance which was isolated from the chamber ground. All experiments were conducted within the 'Daedalus' vacuum facility, which provided a base pressure of 0.2 mPa and a maximum working pressure (with propellant flow) of 27 mPa.

The thruster was operated and characterized in two modes. Initially the high voltage power supply was used to generate a plasma between the neutralizer grid electrode and the ground return. The current voltage characteristics of this discharge was then recorded while using a small range of Krypton propellant flows. This initial characterization indicated the upper limit of current which cold be drawn and allowed an assessment of what flow conditions were required for stable operation. The maximum current measured at this stage also determines the maximum current which could in principle be drawn by the anode once activated.

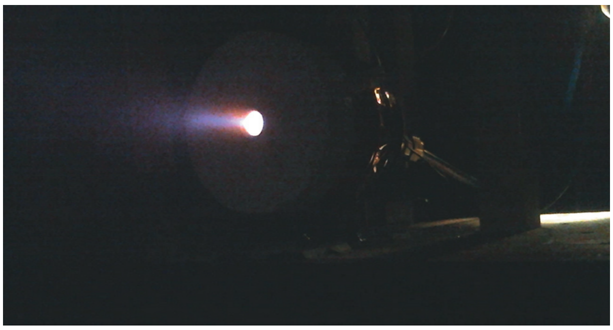


Figure 2: Photograph of the QCT-40 firing while mounted on a pendulum thrust balance within the daedalus vacuum facility.

Having established a stable, maximum current, configuration the neutraliser current was maintained at a constant value and the anode supply was then activated in parallel to the neutraliser supply. The anode voltage was increased from zero until the discharge became unstable while the current drawn to the ground and neutraliser electrode was measured using an ammeter. The neutraliser supply voltage was found to vary when the anode voltage was increased and this was also recorded. The above procedure was then repeated while using carbon dioxide as the propellant.

III. Results

The results of the initial neutraliser characterisation are shown in Fig 3. While operating the neutraliser on krypton, it was found that the maximum current which could be drawn to the neutraliser electrode was limited to 30 mA across the range of propellant flows surveyed. However, when operating using carbon dioxide, the maximum current increased to 40 mA, which was again apparently insensitive to changes in the propellant flow.

Comparing the neutraliser current voltage trends while operating on the two gases, distinct features were found at higher current levels. In the case of the carbon dioxide discharge, step-like increases in the discharge voltage were observed at about 20 mA for each propellant flow condition. These steps corresponded to an average increase in the discharge voltage of approximately 150 V. These steps were not found when operating using krypton, however slight increases in the discharge voltage were found which deviated from the smooth increases at lower currents. This was most pronounced at the 2.78 mg/s flow condition and occurs at a discharge current of 24 mA.

Common between the two gases, the voltage increase slowed close to the maximum current level and the maximum voltage for each flow condition was lower for increasing gas flow rates. The krypton discharge required a significantly higher voltage to maintain the discharge. Comparing the 2.5 mg/s flow cases in Fig. 3, the maximum voltage was recorded at 1.7 kV for krypton and approximately 0.8 kV for carbon dioxide.

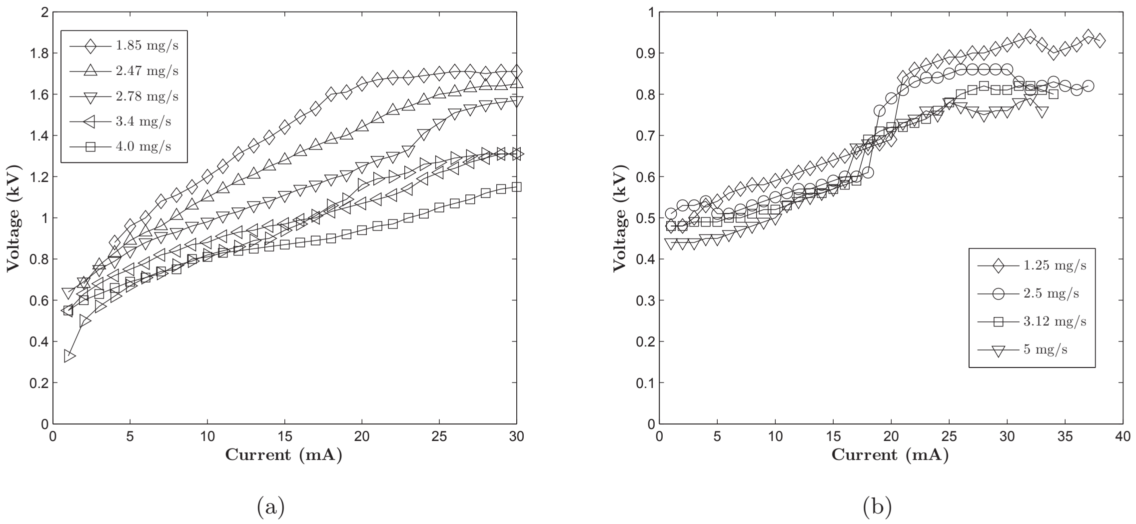
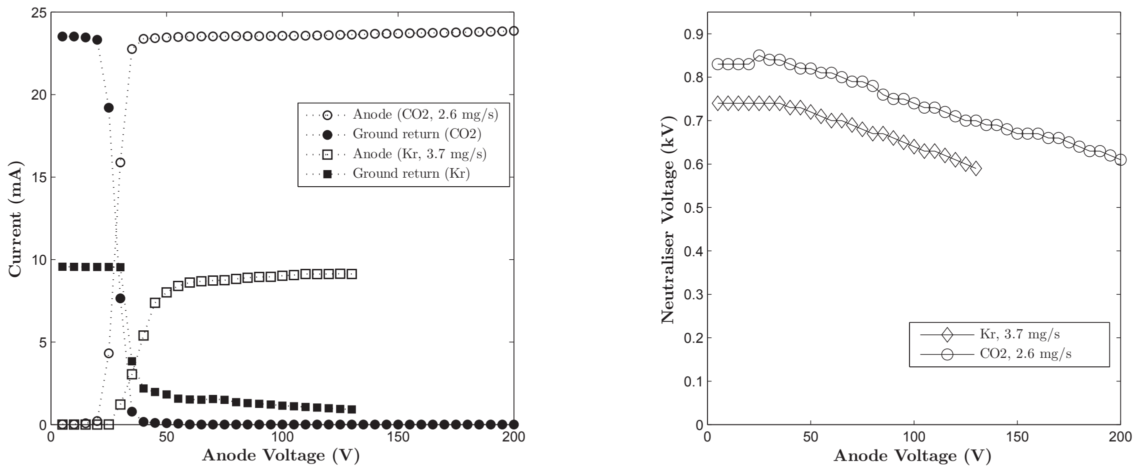


Figure 3: Current and voltage characteristics of the neutraliser discharge while using krypton propellant (a) and carbon dioxide (b).

The operating characteristics of combined neutraliser/anode operation for krypton and carbon dioxide are shown in Fig. 4a. Next to this in Fig. 4b the neutraliser voltage is plotted as a function of the anode voltage for the same discharge conditions. The propellant flows selected for each gas in this part of the study were 2.6 mg/s for carbon dioxide and 3.7 mg/s for krypton. These propellant flows were selected on the basis of the stability of the discharge when voltage was applied to the anode. Propellant flows below these limits priduced an unstable discharge for both carbon dioxide and krypton.

While operating the QCT-40 with the anode, it was found that the discharge was unstable when the



(a) (b)

Figure 4: (a) The current drawn to the anode and ground return electrode as a function of the anode voltage while operating on carbon dioxide, at a mass flow rate of 2.6 mg/s and krypton at a mass flow rate of 3.7 mg/s.(b) The neutraliser grid voltage as a function of the anode voltage for the two operating conditions shown in (a).

neutraliser was operated at high currents. This resulted in the requirement to limit the pre-set neutraliser current to 10 mA when using krypton and 24 mA when using carbon dioxide, despite having operated the neutraliser discharge at a maximum current of 30 and 40 mA when using krypton and carbon dioxide respectively, as shown in Fig. 3.

One aspect of the QCT-40 operation which we wished to investigate was the current path taken when both the neutraliser and anode electrodes were powered. Initially, at low anode voltages, no current is drawn to the anode and the current is drawn entirely to the ground return electrode. At an anode voltage of approximately 40 V, the current path switches and the current drawn to the ground electrode decreases to zero while the anode current increases to the same level as that which was drawn to the ground electrode at zero anode voltage. This 'switch' happens over the course of approximately 20 V and occurs in a similar fashion when operating with both krypton and carbon dioxide.

At higher anode voltages, operation using krypton became difficult as the plasma became unstable for anode voltages above 130 V. In contrast, operation with carbon dioxide remained stable for anode voltages up to 200 V. Since operation using carbon dioxide allowed a higher maximum anode current and voltage, the anode power reached a maximum of 4.8 W, compared to about 1 W when using krypton.

IV. Conclusions

A prototype quad confinement thruster has been operated using a neutraliser based on an inertial electro static confinement device. The thruster was operated using krypton and carbon dioxide propellants and current-voltage characteristics of both the neutraliser and anode discharges were recorded. Instabilities were encountered in the discharges while operating on both gases when the neutraliser current and anode voltage were above 10 mA/130 V for krypton and 24 mA/200 V for carbon dioxide. Since operation using krypton did not allow an anode power above 2 W and carbon dioxide allowed up to 5 W, carbon dioxide may be a promising propellant choice for future investigations. These low anode currents limited the power which could be supplied to the anode. While the use of carbon dioxide appeared to increase this limit, a more fundamental limit related to the area of the neutraliser grid and the anode may also be a factor. When the anode voltage was increased above 40 V (for both propellants) the current drawn to the ground electrode, which is a 45 mm diameter by 40 mm length tube (113 cm^2), goes to zero and the current is instead drawn to the anode, which is a 3.17 mm diameter tube with an exposed end of 7 mm (1.3 cm^2). This change in the exposed electrode surface area of a factor of ∼100 could be a factor limiting the current which could be drawn to the anode.

Future Work

While the neutraliser was successfully operated at a discharge power of 50 and 40 W for krypton and carbon dioxide respectively, the anode discharge was limited to 1–5 W. Future work will investigate the limitations set on the anode current, in order to increase the anode power. The geometry of the device will be revisited, since the spacing between the neutraliser electrode and the ground return, as well as their surface areas relative to the anode, may fundamentally limit the power which can be delivered to both the neutraliser and anode discharges. The performance of the thruster will also be characterised through direct thrust measurements using a pendulum balance.

Acknowledgments

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