Verification of Exhaust Quasineutrality in a Pulsed Cathodic Arc Thruster Testbed

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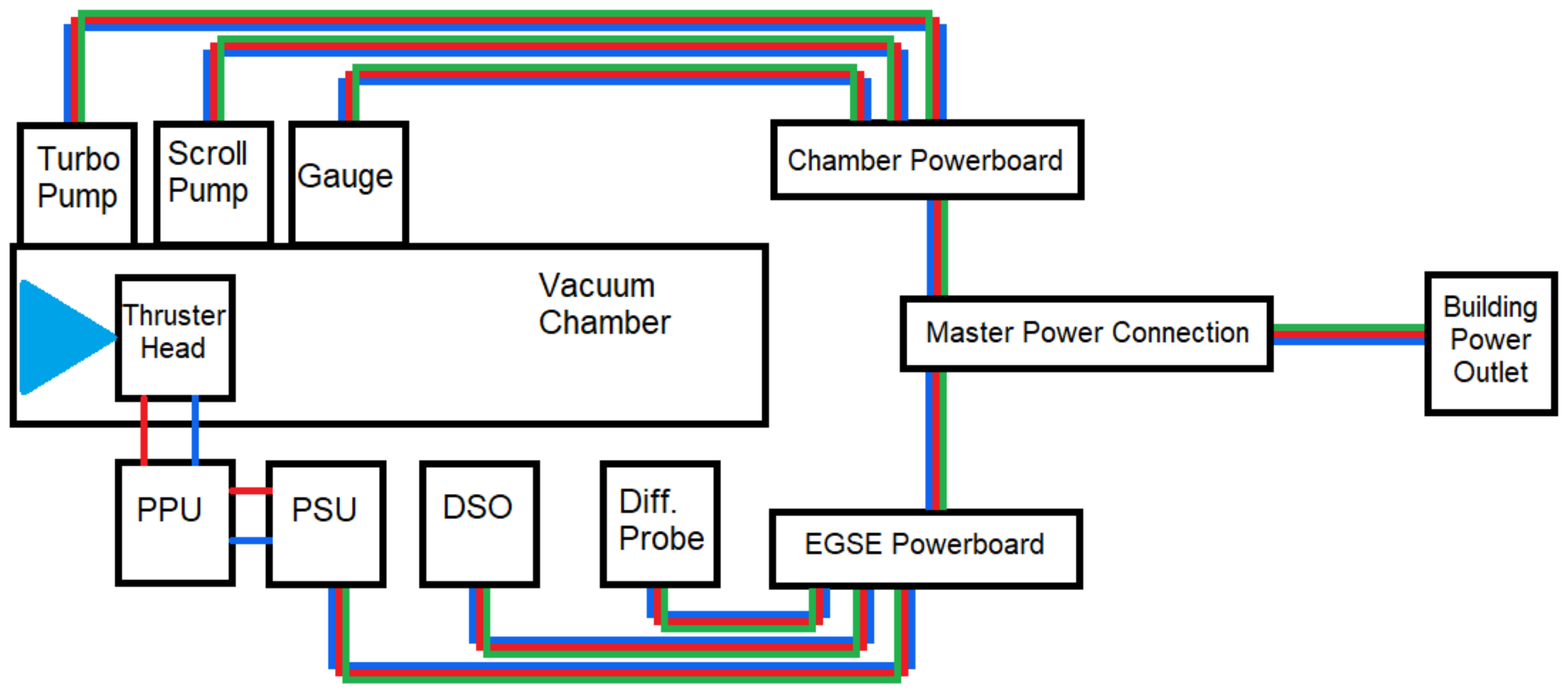
Introduction

Electric propulsion systems have become more common on-orbit in recent years due to their many benefits[1]. Most flight-rated systems generate thrust by producing an ion beam directed away from the spacecraft, which must then be neutralised to ensure proper spacecraft operation [2]. Despite decades of flight heritage, neutraliser lifetime is one of the more common life-limiting factors for Hall and ion thrusters [2, 3]. Systems currently under development that generate neutral plasma jets do not require a neutraliser, removing failure modes and reducing system complexity [4]. Neumann Space has developed to flight-readiness a pulsed cathodic arc thruster, which does not require a neutraliser. Here we present work done using the inner surface of a steel vacuum chamber as a Faraday cup to capture the exhaust of a pulsed cathodic arc thruster testbed, instrumented to measure charge flow and verify exhaust neutrality.

Equipment and Methods

Pulsed cathodic arc thrusters are based on plasma deposition sources used for industrial coating applications and are being adapted to provide propulsion for small spacecraft. A large part of the benefits they bring to spacecraft design and operations derive from the physics involved in the plasma generation processes [5]. When an arc is struck, plasma arises from generation sites on the surface of the conductive cathode; these sites are small, mobile, transient, and energetic, and are often called “cathode spots” in the literature [6]. Processes within the cathode spot lead to the explosive release of a quasineutral plasma, comprised of ionised cathode material and a Maxwellian electron population [5]. While the neutrality of the plasma plume is well attested in the deposition community, the different requirements of a propulsion system require its verification in a propulsion context, using appropriate instruments to determine charge flows [4-6].

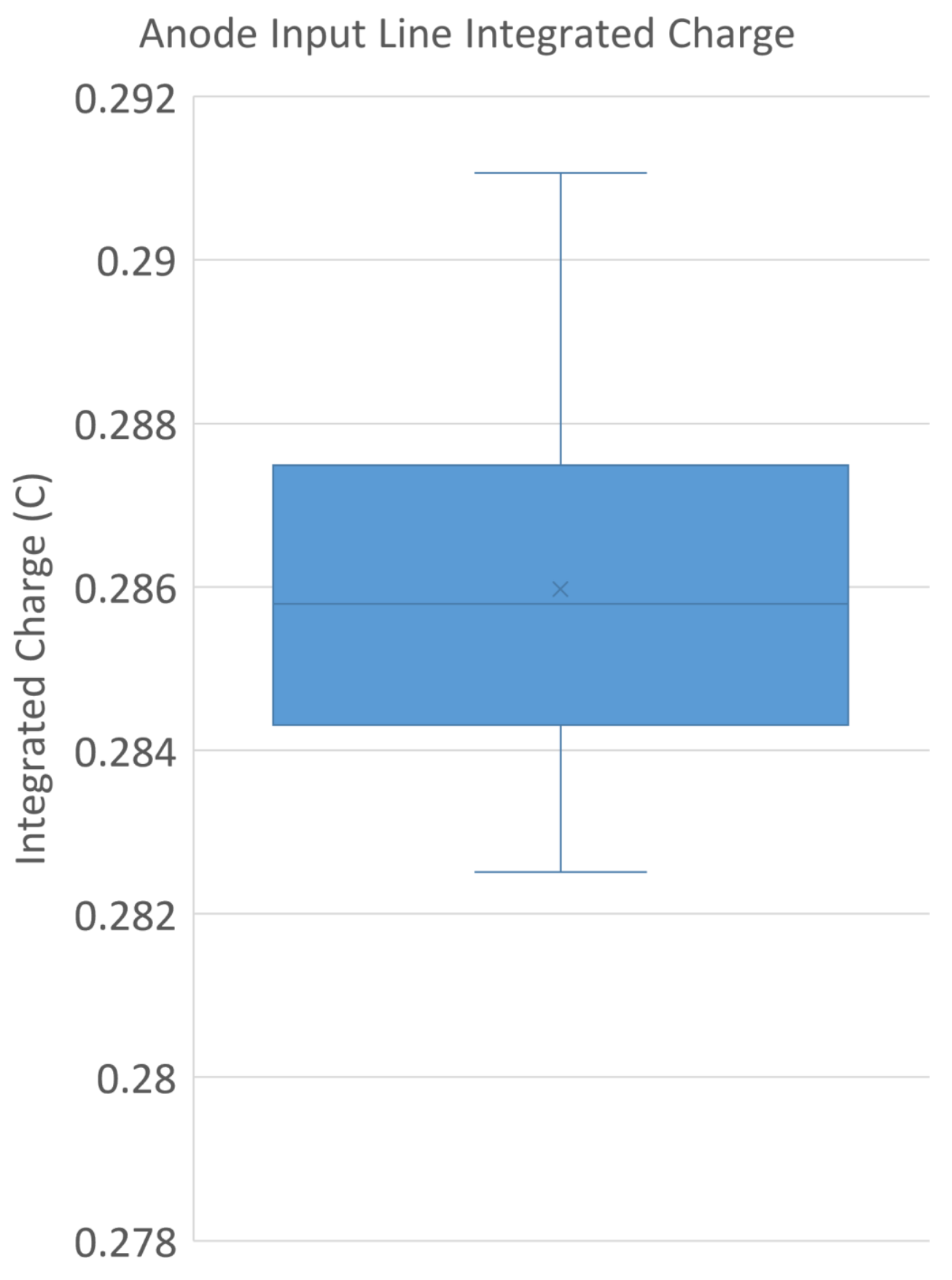


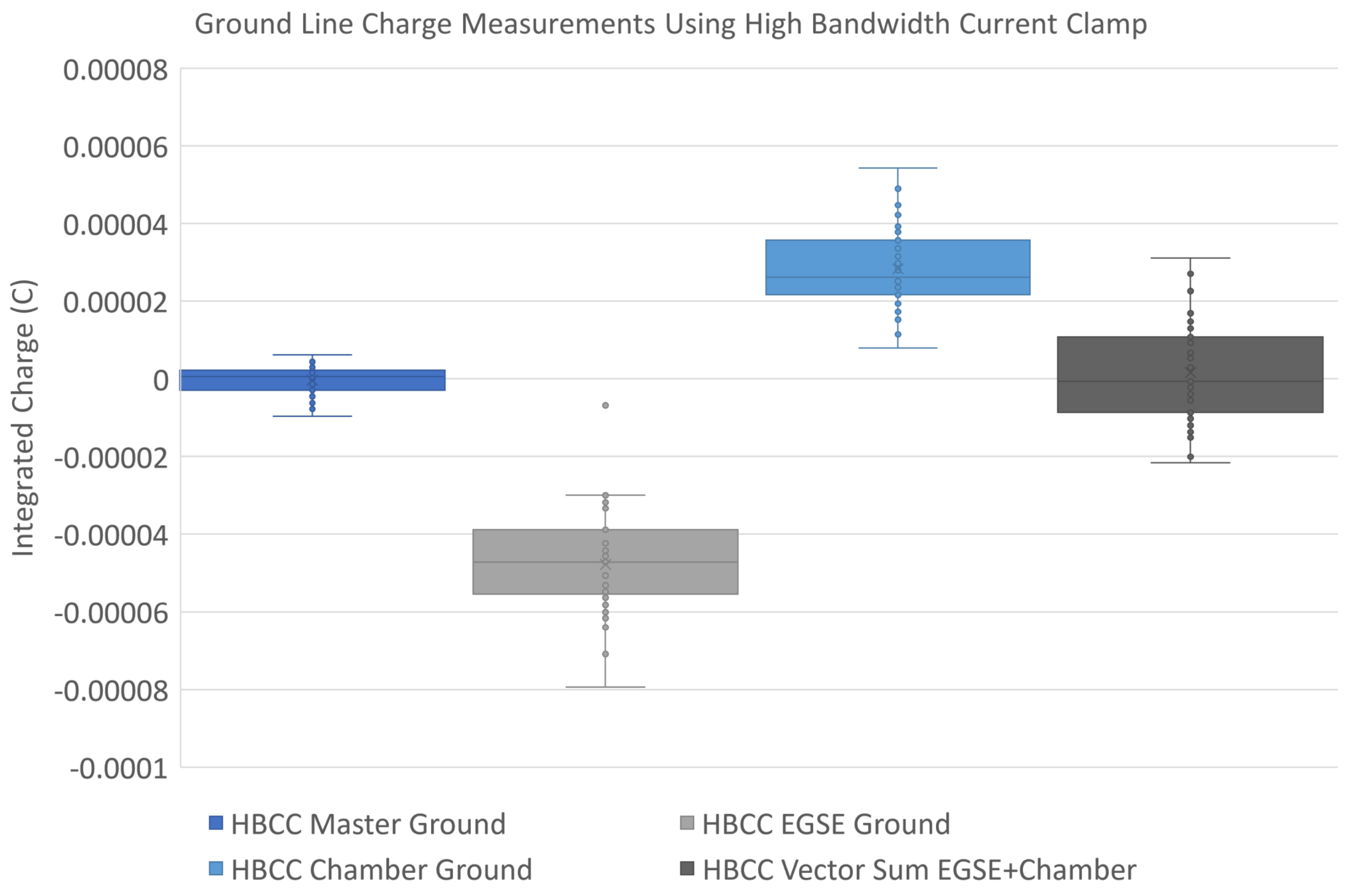
In this work a representative anode-cathode array was placed in vacuum such that the plasma stream was directed at the stainless-steel chamber wall, while the power processing and pulse forming hardware operated out of vacuum to facilitate instrumentation, with a sketch of the experimental setup shown above. In the figure, triple-lines of blue, red, and green indicate standard AC power connections, with neutral, active, and earth lines respectively. Separate red and blue lines are, respectively, positive and negative DC connections. Instruments included a set of Rogowski coils (Pico TS 325), a differential probe used for signal triggering (EEVBlog HVP-70), a high-bandwidth current clamp (Cal-Test CP6770-EU, hereafter HBCC), and a Keysight DSOX 1204A digital storage oscilloscope.

The instruments measured currents conducted to ground from the chamber walls, which acted as a Faraday Cup, and other equipment mounted on the chamber. To facilitate this, all chamber equipment was fed from one powerboard, while all other electrical ground support equipment (EGSE) was fed from a second, and both powerboards were fed from a master power cord, enabling the instrumentation of the master ground line as well as the ground lines of the test and chamber equipment powerboards. Comparison of measured currents along the various ground lines to the measured electron currents along the power input lines enables quantification of the degree of neutralisation inherent in the plasma ejection processes.

Results and Discussion

High current Rogowski coil measurements on the input lines indicated 286±2mC transited the anode line to the chamber, powering the arc, with the uncertainty bound corresponding to a single standard deviation. The bandwidth and resolution of the Rogowski coil on its lowest current scale setting was insufficient to capture all aspects of the master ground line, thus the HBCC was used to capture this information, with the charge conducted along the master ground line to the building ground found to be -0.35±3.56μC, with the uncertainty again corresponding to 1 standard deviation. Instrumentation of the chamber and EGSE ground lines indicated damped oscillations in antiphase, with the initial peak dominating the integrated charge value; these have been plotted below at right, with a positive value indicating positive charge conducted from the relevant powerboard to the junction with the master ground line. The oscillation frequency corresponded to that of an LC oscillator with the line inductance of the combined cable lengths and the input capacitance of the benchtop power supply feeding the PPU; the vector sum of the two measurements is also plotted below for reference. All measurements in each set were across 50 plasma pulses.





From these results we conclude that no excess charge leaves the thruster head and returns to building ground, and even when considering outliers, the plasma neutralises to one part in 10 000. We therefore consider that the exhaust of a pulsed cathodic arc thruster is self-neutralising, and that an exhaust neutralisation system, with all its attendant complications, is unnecessary.

References:

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