

Use of a Magnetized Cascade Arc Source in TCSU to Enable RMF Formation of High Temperature FRCs

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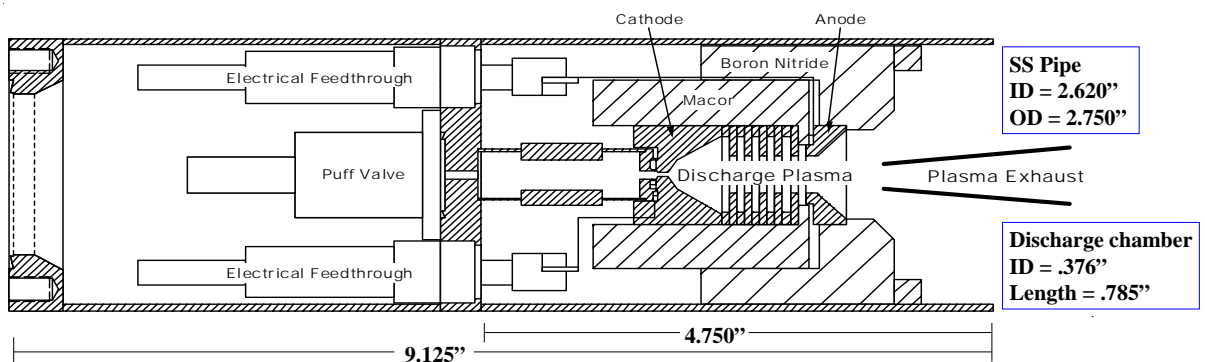
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Abstract

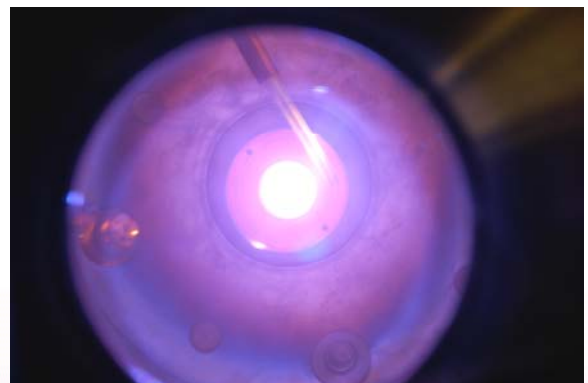
TCSU can produce 200 eV FRC plasmas out of a weakly ionized gas by means of an azimuthally rotating magnetic field (RMF) and a steady axial bias field. The seed plasma for the RMF driven FRCs is produced by an ultra-high vacuum compatible, magnetized cascade arc source (MCAS)*. The arc source has been constructed to translate into the TCSU end section where it is fired in the presence of an approximately 150 mT axial magnetic field. This allows the $n_e=3.3 \times 10^{19} \text{ m}^{-3}$, $T_e=10 \text{ eV}$ gun plasma to stream along the axial field to the confinement section where, along with a necessary mid-plane puff of neutral deuterium, it can be used to form and sustain the FRC. Final FRC parameters depend on the condition of the gun plasma and deuterium puff parameters, as well as the degree of deuterium recycling from the wall. A fast ion gauge is used to measure the neutral pressure in the confinement section at the moment of FRC formation. The effect of varying plasma gun conditions and neutral puff parameters on FRC performance is currently being studied and results will be shown.

*(G. Fiksel, *et al* 1996 *Plasma Sources Sci. Tech.* 5 78)

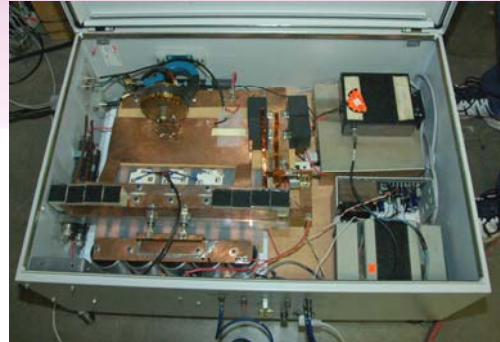
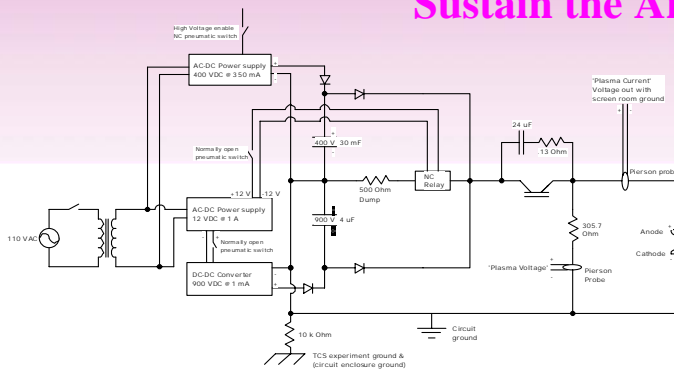
Schematic of the MCAS Currently in Use in TCSU



The plasma gun (MCAS) currently used in TCSU is designed to be in a clean, ultra-high vacuum environment. The plasma gun is also designed to be translatable and as robust as possible. A cross-sectional view of the plasma gun is shown above. The cathode and washer stack fit inside a Macor, or machinable glass ceramic, sheath and the anode is held in place by a boron nitride ferrule. All of the components are contained within a stainless steel pipe and are compressed using a retaining ring. This robust design not only makes it easy to change the dimensions of the plasma discharge chamber but the anode and cathode are easily replaced also. The electrode material is chosen to have the lowest possible electrical erosion rate but must still be machinable. All arc discharges to date with this plasma gun have been made using molybdenum but carbon electrodes and washers have been made and will be tested shortly. More exotic materials such as silver tungsten alloys may be used also.

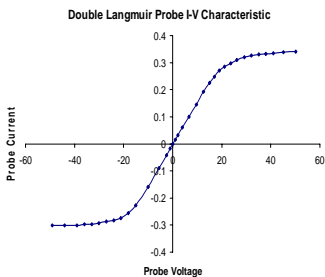


A 3 Kilojoule, IGBT Controlled Power Supply is Used to Form and Sustain the Arc Discharge



A 3 kilojoule, IGBT (integrated gate bi-polar transistor) controlled power supply is used for initial breakdown and arc sustainment. The use of IGBTs makes it possible to vary the plasma discharge time from as little as 100 microseconds to over 15 milliseconds. As shown above, a 900 volt potential is applied across the anode and cathode for initial breakdown. This initial voltage is supplied by high voltage 4 μ F capacitors. After the initial breakdown is achieved the 30 mF capacitors supply the charge necessary for arc sustainment. The IGBTs are protected by a 24 μ F snubber circuit. A current transformer probe is mounted inside the power supply enclosure to measure the plasma discharge current. The plasma voltage is measured using a high resistance voltage divider.

A Double Langmuir Probe has Measured n_e and T_e



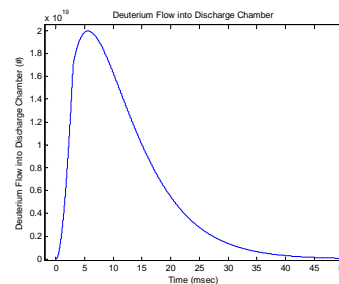
- A double Langmuir probe was used to determine T_e and n_e
- Probe was positioned in plasma exhaust approximately 3.5 cm from anode on axis
- Probe tips are tungsten probe tip length is 0.38 cm probe tip diameter is 0.05 cm

• Graph above shows a shot to shot Langmuir probe sweep for a 400V discharge formed 6 ms after gas puff gate signal.

• Usual double probe analysis $\frac{dI}{dV}\bigg|_0 = \frac{e}{kT_e} \frac{i_{1+} \cdot i_{2+}}{i_{1+} + i_{2+}}$ reveals T_e as 9.83 eV

• Bohm ion saturation current $I_{i+} = .61eA_s n \sqrt{\frac{kT_e}{M_i}}$ yields $n_e = 3.34 \times 10^{19} \text{ m}^{-3}$

Flow Analysis to Determine Mass Flow Rate and Ionization Fraction



- Solving simple volume filling equation

$$\frac{dp}{dt} + \left(\frac{\tau A_o a}{V}\right) p = \left(\frac{\tau A_v a}{V}\right) p_v$$

to determine plenum fill pressure

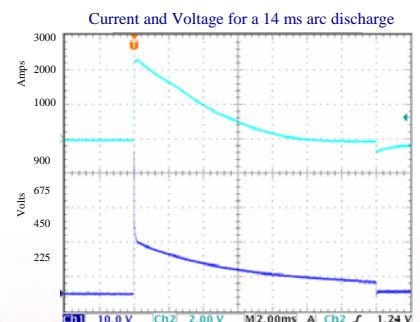
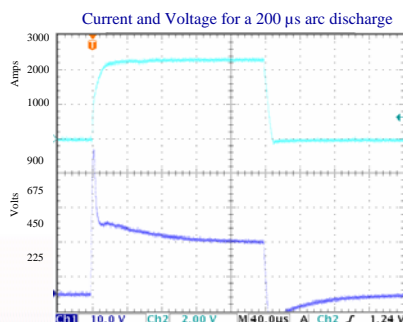
• Use plenum pressure $p(t)$ to determine mass flow rate through cathode orifice

• At a valve pressure of 28 psig the maximum MCAS flow rate is approximately $1.37 \times 10^{22} \text{ #D}_2/\text{s}$.

• Preliminary power balance shows the ionization percentage to be approximately 30% with large error bars.

The MCAS Discharge is Reproducible Under Different Conditions

- The plasma discharge duration is easily varied.
- Current and voltage decay times are always uniform
- Droop in the current transformer probe is evident in discharges of 6 ms or more.
- Quality design and construction of plasma gun eliminates extraneous arcing and insures repeatability.

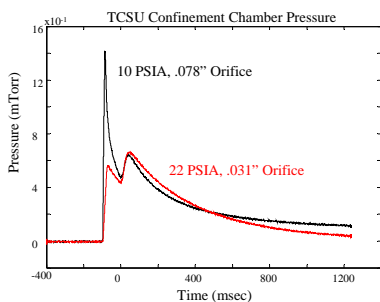
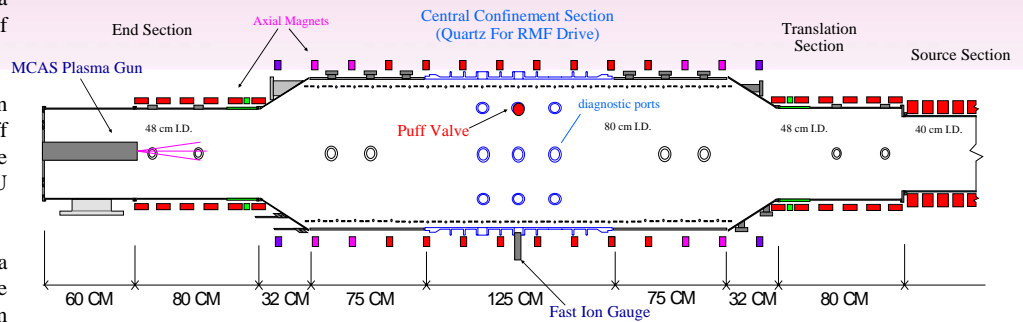


A Fast Ion Gauge has been Used to Characterize MCAS Performance as well as Gas Puff Regimes and Wall Pumping in TCSU

• This is a scale drawing of the TCSU experiment at the Redmond Plasma Physics Lab, University of Washington.

• The locations of the MCAS, fast ion gauge (FIG), and mid-plane puff valves are shown along with the pertinent dimensions of the TCSU downstream sections.

• A 1100 Liter/sec Turbo pump and a 1500 Liter/sec Cryo pump are mounted on the upstream section (right hand side of drawing) which is not shown.

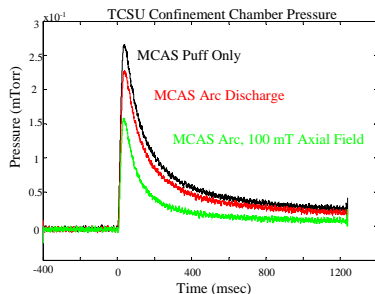


• Two typical pressure profiles are shown. Each curve represents the pressure in the confinement chamber due to the gas input from the mid-plane before time zero (RMF fired) and the gas from the MCAS slightly after time zero.

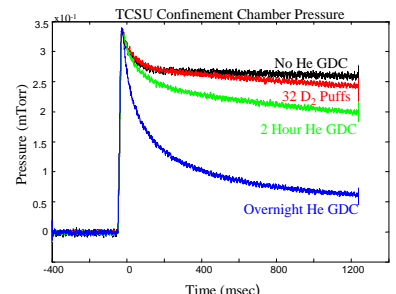
• With the help of the FIG we have been able to replace our large orifice puff valves with smaller orifice puff valves and operate them at positive pressure to eliminate the risk of impurity introduction through the gas fill system.

• The FIG has also made it easy to reach the desired pressure in the confinement chamber more efficiently thus reducing any un-necessary gas which only goes into loading the vacuum chamber walls and eliminating the benefits of glow discharge cleaning.

• The graph to the right shows the pressure in the confinement chamber due to the MCAS. The location of the FIG is such that all energetic, ionized species are not measured. The addition of an axial magnetic field allows the ionized gas to stream to the confinement chamber quickly so they are the only constituents from the MCAS present when the RMF is fired at time zero.



• Wall pumping rates can be measured by puffing deuterium into the vacuum chamber with all pump valves closed and then measuring the drop in pressure as a function of time with the fast ion gauge.

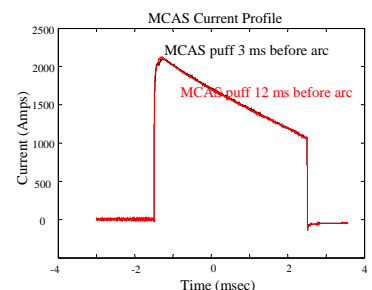
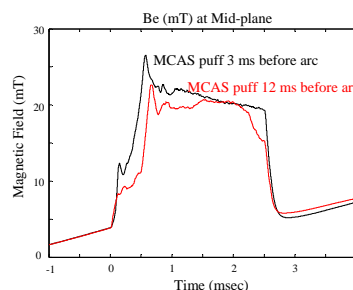


• These results at right clearly show an increase in deuterium wall pumping rates after helium glow discharge cleaning as shown by the much more rapid drop in chamber pressure as deuterium is adsorbed onto the walls.

The MCAS Discharge is the Sole Form of Pre-Ionization in TCSU

• All FRCs to date in TCSU are formed by RMF start-up from a single MCAS discharge and a necessary mid-plane puff of neutral deuterium.

• Because the RMF power input to the FRC is many orders of magnitude greater than the power input from the MCAS, changing gun conditions does little to affect the overall performance of the FRC.



• The most noticeable change in FRC performance is observed when the MCAS gas puff gate is set early enough so that a large amount of neutral deuterium can escape the gun before the arc occurs. Although this can probably be controlled by mitigating the amount of gas injected into the confinement chamber from the mid-plane, it is best to control the FRC gas inventory with the mid-plane puff valves for repeatability.

• MCAS gas puff timing is such that there is just enough gas present in the discharge chamber for breakdown to occur when the arc is switched on.