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COMMISSIONING OF A FUSION COLLIDER FOR INTERSTELLAR PROPULSION

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Abstract

A prototype colliding beam accelerator has been fabricated for the study of a fusion-based propulsion concept for interplanetary exploration. The purpose of this prototype is to demonstrate collider luminosities commensurate with the requirements of this application. Direct emission of fusion daughters generates the exhaust velocities required for spacecraft speeds in excess of 1% of the speed of light. Past attempts at nuclear fusion energy production with colliding beams have been limited by Coulomb scattering, a deficiency overcome in this collider architecture. Instead of using fusion fuels such as p/Li7 and He3/He3 capable of generating the required thrust characteristics, this prototype employs deuterons. DD fusion produces neutrons that provide a convenient luminosity detection channel. The commissioning campaign described in this paper operates the collider at a peak beam kinetic energy of 54 keV at the interaction point. Axial confinement and radial focusing are achieved electrostatically. Proposed analysis of imminent beam measurements of axial (longitudinal) and radial (transverse) beam dynamics and beam lifetime are presented.

LOW LUMINOSITY COLLIDER

The fusion reactor architecture used in the proposed propulsion system [1] consists of an electrostatic charged particle trap [2-4] that brings two ion beams into collision with equal and opposite momentum. The goal is to directly emit a focussed flux of fusion daughters as an exhaust stream capable of generating a spacecraft velocity change of at least 4.6% of the speed of light [5].

Given the current state of accelerator physics, increasing collider luminosity by several orders of magnitude is the greatest challenge. A terrestrial prototype collider has been designed and built in order to begin the experimental process of increasing the achievable luminosity of this architecture. Instead of using appropriate fusion fuels for propulsion, this terrestrial prototype collides deuterons. By measuring luminosity [6] from the flux of emitted neutrons, and adapting the operations and technologies employed, the goal is to gradually achieve the required luminosity.

Many unique physics and technology issues arise from the proposed collider architecture. At a fundamental level, it makes no sense to concentrate on increasing luminosity if the single particle optics and beam dynamics are not already well understood. For this purpose, a second apparatus was designed and fabricated. Figure 1 contains a photograph of this "Lifetime Demonstrator" while it was un-dergoing vacuum cleaning via a controlled gas discharge.

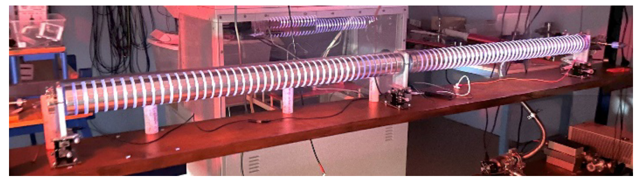

Figure 1: Luminosity Demonstrator apparatus while undergoing a gas discharge vacuum cleaning.

The physical structure of this is sketched in Fig. 2. Two quartz tubes (central green rectangles) are sealed at the center and ends by O-rings compressed by custom-fabricated stainless steel fittings. A future iteration of the apparatu will replace the O-rings with vacuum epoxy. The central fitting is 18' in length, and each quartz tube is 48" long. On either side of this structure exists various vacuum gauges, pumps, and valves. While on one side a destructive Faraday cup is used measure deuteron intensity, the other side is connected to the deuteron source. The axis formed by this structure is referred to as the axial direction, similar in some ways to the longitudinal coordinate in circular accelerators.

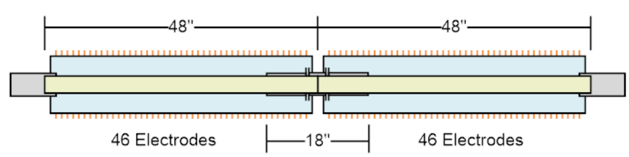

Figure 2: Illustration of the structure of the Lifetime Demonstrator apparatus.

Given the absence of steering magnets or other comparable devices in the radial (perpendicular to axial) direction, precise relative alignment of the three stainless steel fittings is employed. Figure 3 contains a picture of the commercial translation stages employed under each fitting.

Figure 3: Picture of the commercial translation stages employed to align the center and axial edges of the structure in Fig. 2.

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Around this vacuum structure exists electrodes that are electrically charged to a prescribed sequence of voltages. There are 46 such electrodes on either side of the apparatus, with voltages applied that generate mirror-symmetry about the central deuteron collision point.

As can be seen in Fig. 4, these electrodes are strips of adhesive aluminum tape wound around two transparent plastic tubes. Electrical connections are made with copper alligator clips soldered to lengths of standard solid-core copper wire. The plastic tubes are connected to the stainless steel vacuum fittings to insure alignment and long-term structural stability. The copper wire is held firmly in place by two lengths of plastic square tubing through which appropriately space holes were drilled.

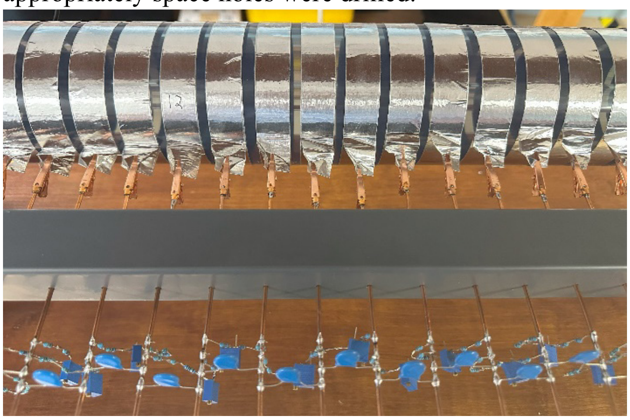

Figure 4: Picture of the array of electrically charged electrodes (above) and the network of resistors and capacitors (below) that distribute high voltages along the array.

A negative high voltage power supply capable of -60 kV is connected to the apparatus of Fig. 2, with the ground terminals attached to the stainless steel fittings on either end and the negative high voltage connected to the central fitting. This high voltage is then transmitted to the individual electrodes via the network or resistors and capacitors picture in Fig. 4. The resistance between each pair of electrodes was measured and tuned with a 10-turn potentiometer. The high voltages are determined to provide axial confinement of injected deuterons and simultaneously provide radial focusing.

During long-term deuteron storage the injected beam undergoes rapid decoherence to zero net current. During and immediately after injection, the beam image currents deposited on the electrodes are provided a low impedance pathway between electrodes via the capacitors between each electrode.

DEUTERON SOURCE

In contrast to the large terrestrial prototype built to achieve high luminosities [6], this Lifetime Demonstrator has a comparably small vacuum volume, on the order of 300 cc. The neutral gas accompanying the injection of the deuterons was found to be too large for this apparatus. Therefore, an alternative ion source was developed for the specific demands of this work, named the Accumulator Ion Source. The architecture of this source is a merger of the Penning traps [2] and sputter-ion vacuum pumps. In a sputter-ion pump, trapped electrons ionize gas molecules, increasing the population of electrons and simultaneously accelerating the resultant positive ions in the axial direction. The same axial electrostatic potential that accelerates out the ions also traps the electrons. A picture of the core of the Accumulator is shown in Fig. 5. A 6” length of alumina tubing is vacuum epoxied between two commercial stainless steel pipes. Around the alumina tube are eight stainless steel electrodes separated by plastic spacers. The spacers also serve to maintain separation between the various high voltage wires (red) that set the electrostatic potential of each electrode.

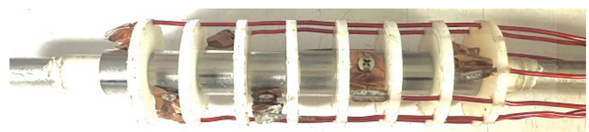

Figure 5: Picture of the vacuum and electrostatic core of the Accumulator Ion Source.

Figure 6 contains a sketch of the electrodes in Fig. 5 (red) and the axial electrostatic potential (black) when voltage are employed appropriate for ion accumulation and electron (blue) confinement. This entire structure is immersed in a solenoid in order to provide Penning-style radial confinement. The solenoid if pictured in Fig. 7.

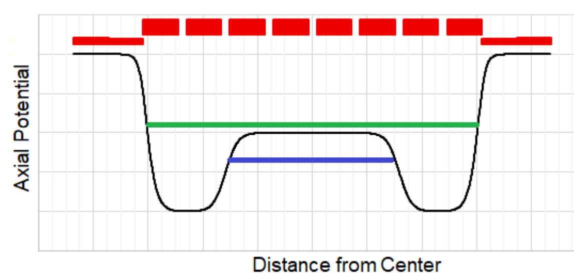

Figure 6: Illustration of the Accumulator Ion Source.

A fast electrical vacuum valve off to one side of the Accumulator core injects a pulse of deuterium gas. The gas pulse is confined in the Accumulator core by a slow, electrically-driven vacuum ball valve on the other side. The gas immediately undergoes a gas discharge due to the axial voltage profile and a brief transient voltage “spark”. This populates the electron distribution and over a span of time converts the deuterium gas into confined deuterons. The total energy of those deuterons are represented by the green line in Fig. 6.

When a ion vacuum gauge confirms that the gas pressure with the Accumulator core has diminished to acceptable levels, the voltage profile of the electrodes are modified to axial compress the deuteron distribution. After opening the vacuum ball valve, the voltage are pulsed in order to extract the deuterons into the Lifetime Demonstrator.

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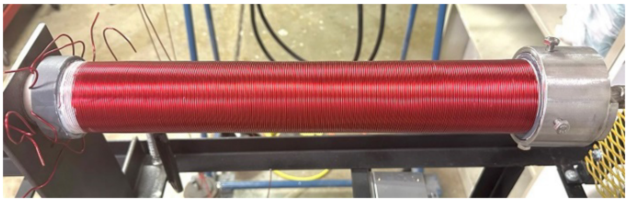

Figure 7: The solenoid magnet employed around the Accumulator Ion Source core. The magnet was still on its winding fixture when this photograph was taken.

CONCLUSION

In order to reach the nearest star within a century with an orbiting scientific probe, a propulsion system based on colliding beam nuclear fusion has been proposed. The achievement of sufficient luminosity to enable such missions represents a challenge to the accelerator physics community. A terrestrial prototype collider has been fabricated to initiate the evolution toward high luminosities in such an accelerator architecture. In order to understand single particle dynamics, a Lifetime Demonstrator has been designed and built. This Demonstrator has required the design and fabrication of an improved ion source based on ion accumulation and simultaneous background gas elimination.

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