H- ION BEAM CHARACTERIZATION

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ABSTRACT

Current density measurements on the H- ion beam of Fermilab`s H- magnetron ion source have been made and show a significant peak at the center of the beam cross-section. The measurements also show movement of the peak current density in the early part of the beam pulse.

A description of the procedure and results will be presented in addition to a discussion of the results based on space charge neutralization.

I. INTRODUCTION

Fermilab employs proton/anti-proton beam collisions for ultra-heavy particle production. Beam formation starts in the source at the Linac. A H- ion source produces a pulsed H- ion beam, which is used for proton and antiproton creation. By studying the H- ion beam characteristics at the source it should be possible to further increase its performance, which may result in a higher quality beam being delivered by the Linac.

One important characteristic of an ion beam is current density. Current density is a measure of the amount of ions in a beam per unit of area. For ultra-heavy particle production purposes a high current density ion beam is desired. For achieving this goal, a substantial H- ion concentration per unit of area is required. However, the particles in the ion beam contain the same charge. The Coulomb repulsion between the particles causes them to diverge from the direction of propagation of the beam resulting in substantial beam loses. This effect is called space charge. Space charge complicates the manipulation of the beam, requiring continuous focusing of the beam as the beam travels.

II. THE H- ION SOURCE

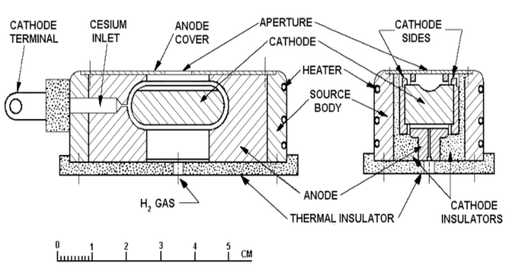

Fig. 1 Fermilab H- Magnetron Ion Source.

The source creates a pulsed ion beam. Beam production starts at the magnetron (Fig.1), which creates the negative ions by surface ionization effects. These ions are extracted and accelerated into the Linac. The H- magnetron resembles a diode in operation. It mainly consists of the magnetron body, which serves as the anode, and a cathode made of molybdenum. Both parts are electrically and thermally insulated from each other by ceramics. During normal operation, an electric field is created by applying a pulsed voltage of approximately 150V between the cathode and anode. This voltage is called the Arc Voltage.

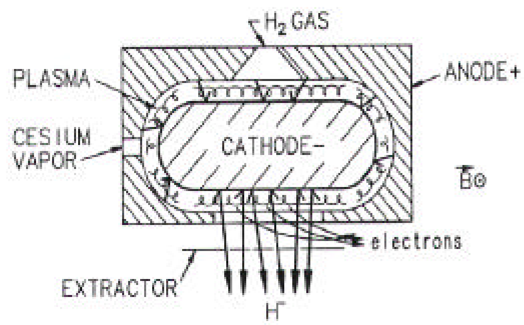

Fig. 2 Ion production by the magnetron.

A magnetic field is applied through the magnetron, perpendicular to the electric field (Fig.2). The potential difference between the anode and the cathode causes electrons at the surface of the metal cathode to overcome the work function of the metal. The surface is coated with a 0.6 monolayer of Cesium, which facilitates this process by decreasing further the work function. This increases the number of ejected electrons from the surface of the cathode. The trajectory of the free electrons is curved by the magnetic field. Hydrogen gas is injected into the volume between the anode and cathode. The Larmour radius of the electron is smaller than the spacing between the cathode and anode, making the electrons travel in long spirals. This efficiently ionizes the hydrogen gas. The conditions inside the cavity create a dense plasma (Fig.3). Protons are obtained from the hydrogen in the plasma. The protons are accelerated towards the cathode and collide with the cathode surface capturing by different methods two electrons.

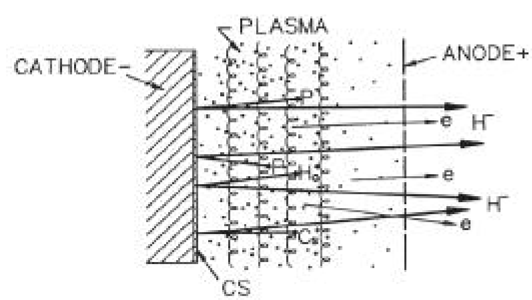

Fig. 3 Ion production process.

An extractor at a distance of ~2mm extracts H- ions and electrons from the magnetron. A voltage of 15 –22kV exists between the extractor and the magnetron anode. The extractor voltage is pulsed to reduce sparking between the source and the extractor. The extracted particles are deflected by a 90-degree bending magnet. Since electrons are roughly 1860 times less massive than the hydrogen ions, the Larmour radius of the electrons is substantially less compared with the Larmour radius of the hydrogen ions. This eliminates the electrons from the beam.

The ion beam leaving the magnetron has high current density, which causes the beam to rapidly diverge. To reduce beam divergence, the 90-degree bending magnet poles are tapered to give focusing. The beam continues its path by entering the Cockcroft-Walton 750 kV acceleration column in which a series of electrostatic lenses accelerate and focus the ion beam. The current of the ion beam is then measured by a toroid mounted after the accelerating column.

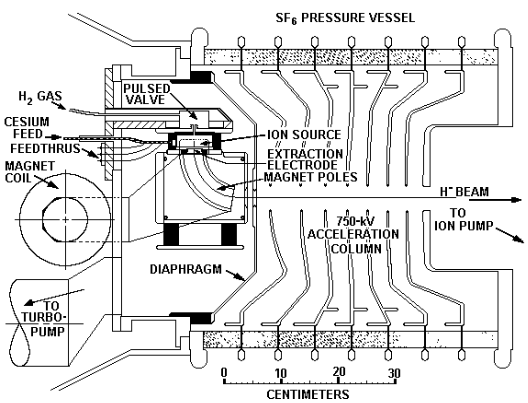

Fig.4 H- Ion Source assembly.

III. DATA ACQUISITION

By measuring current density it is possible to characterize the ion distribution inside the beam. A probe with a linear array of 14 small Faraday cups is used for this purpose. The probe is moved into the beam path by a stepper motor and calibrated screw system. The stepper motor moves the probe in user-defined steps, on which data is obtained. For data analysis purposes, it is necessary that the step size is constant. Each Faraday cup measures a current relative to its position in the beam cross-section. A data file, which contains current readings and positions, is obtained.

An important parameter in current density measurements is position. The position of the probe is determined by using the fact that a stepper motor moves in an integer number of micro-steps, which corresponds to a constant length on the calibrated screw. By measuring the distance the probe moves for a fixed number of micro-steps, the user-defined step length can be converted to an integer number of micro-steps. A micro-step was determined to be 0.0002 inches. The program uses a potentiometer to obtain the first position value, but subsequent positions are obtained by adding the step length to the preceding value. Instead of relying on the position read back from the potentiometer, the motor moves a constant number of micro-steps. This technique has proved to be totally reliable making the position reading in the data file perfectly linear (Fig. 5 (b)). The first value obtained by the potentiometer doesn't compromise the data because the important element in the data is that the step size remains constant.

The Position could have been determined solely by the read back of the potentiometer, but the potentiometer is an old device with significant noise, which makes the position values fluctuate (Fig. 5 (a)). The error in the position was increased by the architecture of the original stepper motor control program. The stepper motor was commanded to move the probe in a constant step size, but since the old code relied on the potentiometer to determine the position, the step size was not constant. Additionally after the motor moved each step, the old code used the position reading of the potentiometer for the position of data file. Since the loop relied on the potentiometer two times per loop, the already existing error on the position reading of the potentiometer doubled (Fig 5 (c)). This severely corrupted the position reading of the data.

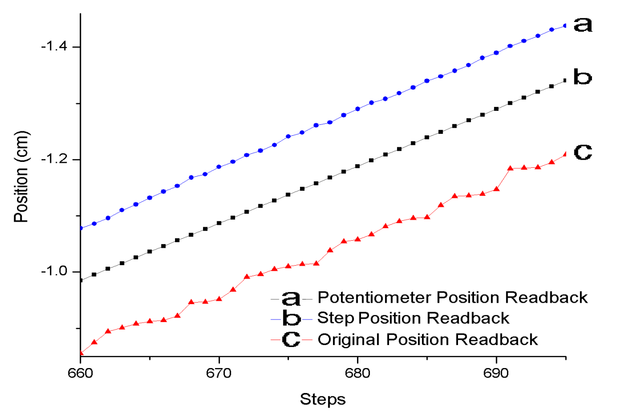

Fig. 5 Faraday probe position measurements.

IV. DATA ANALYSIS

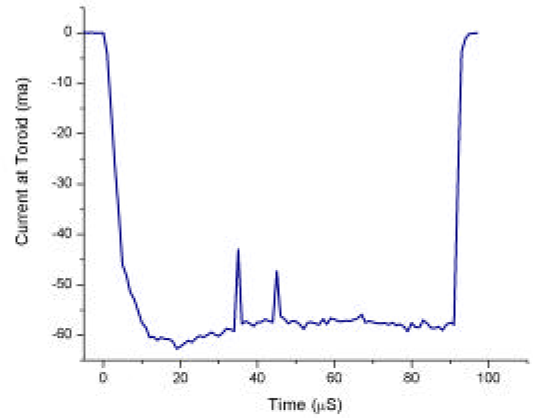

Fig. 6 Ion beam pulse

The beam pulse presently being sent to the Linac, as measured just after the pre-accelerator is shown in Fig. 6.

The current of the beam reaches its maximum ~10µs after the pulse begins. The two spikes created by the chopper indicate the portion of the pulse used by the Linac. The chop width changes for various accelerator operations. The chop duration in this case is from 35µs to 45µs after the pulse begins. It is desired that the portion of the beam used, possesses the highest attainable stability. Since the ion beam is produced in a pulsed manner, it is possible to study how the beam changes through the duration of the pulse.

The data file consists of 15 columns, 1 for position and 14 corresponding to the Faraday cup array, and a number of rows corresponding to the number of probe stops. Since the Faraday cups measure current, not current density, the current readings in the data file are converted into current density readings using the entrance aperture size, 1.6mm diameter, of a the Faraday cups. The data analysis proceeds by plotting the positions and current densities of the data file.

A series of curves are obtained for each channel representing how the current density changed in position (Fig.7). For the sake of clarity other types of plots are also employed (Fig. 8).

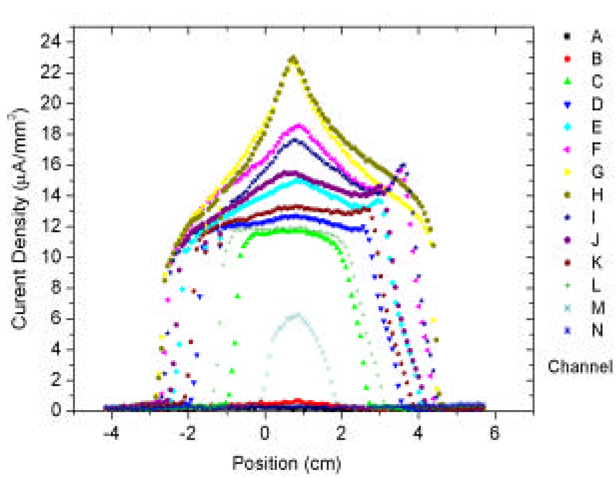

Fig. 7 Current density plots of individual Faraday cups.

It is observed from Fig.7 and Fig.8 that the beam possesses the highest current densities in the center region of the beam. This is caused by charge neutralization, which occurs in a negative hydrogen beam when positive ions partially neutralize the net negative charge in a region. Positive ions are created when the H- ions in the beam collide with neutral atoms in the vacuum. The positively charged ions concentrate in the center of the beam because the electrostatic attraction is highest in this region. This reduces the electrostatic forces between the ions and permits the H- ions to be closer together. The net effect is that the beam slightly collapses and the H- current density in the center of the beam increases.

This center point of the beam is a good reference to measure how the current density of the beam changes in time and how the beam is moving relative to the beam

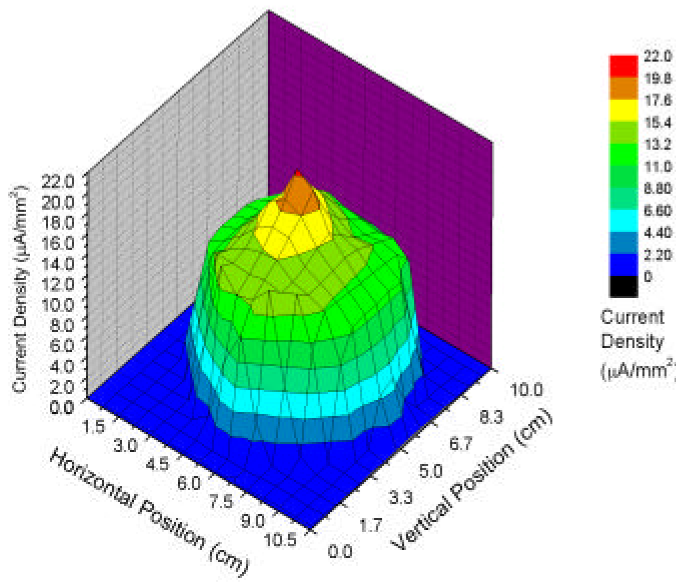

Fig.8 Current density 3-D plot.

propagation axis. Considerable movement of this point could result in beam loses throughout the Linac and make tuning more difficult. By measuring how the position of the highest intensity part of the beam changes it is possible to learn the appropriate interval in which the beam should be sent to the Linac.

When the ions are created in the magnetron, they exit the magnetron through a slit. If this slit were to be projected into the beam spot at the entrance of the acceleration column, it would be a vertical slit. This suggests that if there were movement of the current density peak it would be more appreciable in the vertical direction. The motor step size and the distance between the apertures of the Faraday cups determine the two orthogonal resolutions of the probe. The distance between the apertures, 6.4mm, of the Faraday cups is the larger limiting factor since the length of the step size could be chosen to be appreciably less. This allows the current density measurement to have more resolution in one direction than in other. Therefore the probe was placed in such way that it moved in the vertical direction to obtain the highest resolution in the vertical axis, which is where the current density peak was suspected to have the most displacement.

The readings of the current channels are synchronized with the beam pulse. By changing the time at which the currents are read, it is possible to measure the current density at different times during the beam pulse. With this, a better understanding of the beam dynamics throughout the beam pulse may be obtained. By evaluating the data, the position and intensity of the current density peak at different times in the beam pulse is obtained. The movement of the current density peak is traced by plotting these points. The plotted points are shown in Fig.9.

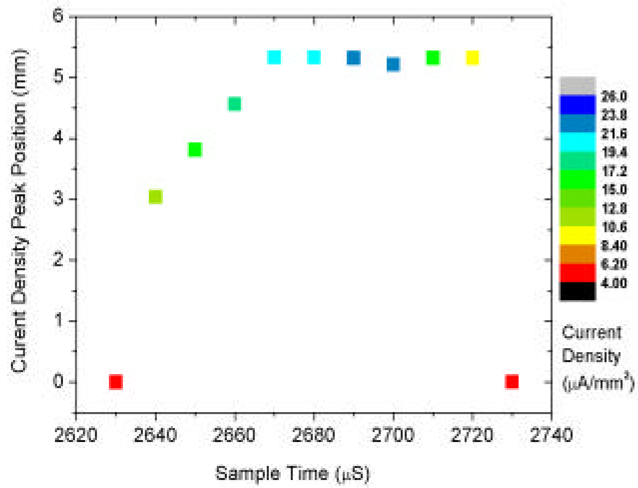

Fig. 9 Movement of the high current density point.

The beam pulse starts at 2620µs and finishes at 2730µs. These are arbitrary times relative to a system start time. From 2640µs to 2670µs there is a movement of ~1mm every 10µs. Although, from 2670µs to 2720µs the net displacement of the peak current density is ~0.1 mm. In addition it is apparent from Fig. 9 that the current density and position of the current density peak of the beam, continues to change considerably for ~50µs after the pulse begins. Also the highest value of the peak current density of the beam occurs between 2670µs and 2700µs. This behavior was observed consistently at different operating conditions, suggesting that it may be an intrinsic property of the beam formation process. By comparing the data in Fig. 6 and Fig. 9 is noted that the interval at which the beam has the highest stability is between 50µs and 80µs after the pulse begins. However, based on the data of Fig. 9, in this portion of the beam pulse the current density peak is changing considerably in position and the current density is not at its maximum. Based on this information, the performance of the Linac may improve by delaying the beam pulse by ~25-35µs.

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