BEVATRON LOCAL INJECTOR DUOPLASMATRON ION SOURCE PERFORMANCE*

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Abstract

Performance tests of the Bevatron Local Injector Duoplasmatron Ion Source using singly charged particles of helium and deuterium are described Initial measurements of the 8.4 keV/nucleon helium 1+ beam and deuterium 1+ beams indicated intensities of 12 particle mA and 8 particle mA respectively. The low energy beam transport line uses a tape wound solenoid and an x-y dipole for matching into the 200 MHz RFQ linac. A beam profile monitor and faraday cup are located in the diagnostic box pumping manifold assembly. The computer control system, the A.C. distribution network, and pulsed gas control system are similar to that of the Local Injector PIG source (1), in that they are housed in an insulated four bay rack in a room directly above the source. The source lifetime of 150 hours is governed by the evaporation rate of the 1 mm diameter tantalum filament, and is increased to several months during operation with the directly heated lanthanum hexaboride filament (2).

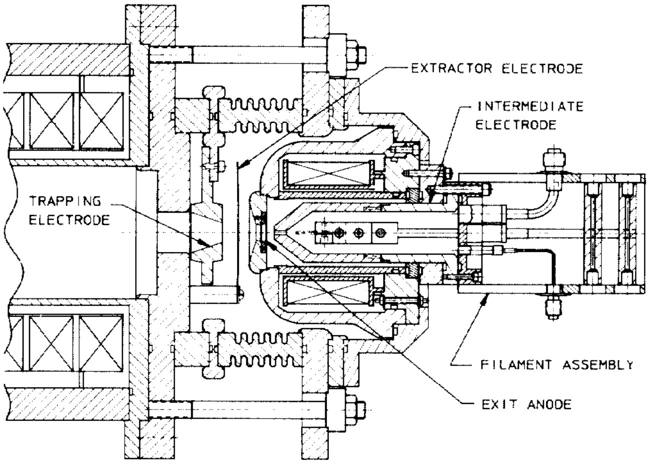
Introduction

The installation of the duoplasmatron facility began in the late summer of 1987 and continued until the first helium beam was accelerated in July of 1988. A steel shielding wall was erected upstream of the linac to allow duoplasmatron installation work to continue on a full time schedule while the PIG injector was running, thus advancing the commissioning date of the duoplasmatron injector approximately six months.

Source Description

A schematic view of the duoplasmatron source is shown in figure 1, and is modeled after the compact design used at the Brookhaven National Laboratory and later at Lawrence Berkeley Laboratory in the local injector. Noteworthy design changes in the source were geared toward minimum down time and ease of service. In this regard the intermediate electrode and the filament assembly can be removed as a unit giving service access the the tungsten exit anode button that measures 1.2 cm in diameter and is 0.5 mm thick. The exit aperture of the button used most frequently with hydrogen gas is 0.5 mm. In addition, the exit end of the intermediate electrode can be removed to allow easy filament inspection or replacement. The source magnet is wire wound producing an axial field at the exit gap of 2500 gauss during normal operation and is cooled together with the filament assembly with freon. The source body is mounted on a dual insulator mini-column which in turn supports the single gap extraction electrode and an electron trapping electrode.

The source lifetime of 150 hours using a 1 mm diameter tantalum filament has been increased to 7 weeks with the installation of the lanthanum hexaboride filament . LaB-6 is an extremely hard material that is obtained from suppliers in a round billet which is then in turn sliced to the desired filament thickness with a diamond saw. The wafer is machined to the required shape by the use of an EDM (Electron Discharge Machine). The boron in the LaB-6 reacts unfavorably with most metals and care should be taken in the selection of the filament support material. Graphite or tantalum can be used with success as well as using rhenium foil sandwiched between the LaB-6 and the filament support structure.



DUOPLASMATRON ION SOURCE

Figure 1.

Because of the brittleness of the LaB-6 material, a compromise exists between sizing the cross section to have the greatest mechanical strength while keeping the operating current within the limits of the existing power supplies. The cross section of the LaB-6 filament shown in figure 2 is 1 mm x 1.5 mm and operates at a current of 75 amperes as compared with the 1 mm diameter tantalum filament at an operating current of 45 amperes. The added bonus in addition to longer lifetime and less evaporation residue inside the filament chamber is that the LaB-6 filament operates at a power level at least a factor of 5 less than that of the tantalum filament. The filament arc current contributes to the uneven heating of the filament as indicated in figure 2 and can be corrected by designing an asymetric filament or by periodically alternating the filament arc connections.

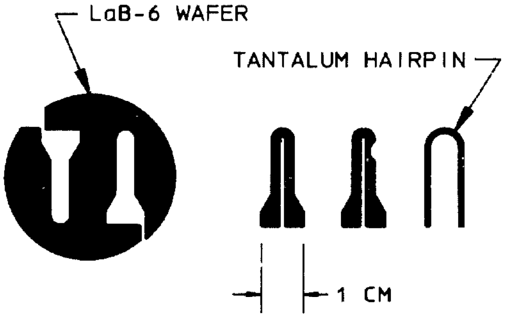


Figure 2. LaB-6 (Lanthanum Hexaboride) Filament

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Ion Source Power and Control System.

The design requirements for the duoplasmatron power supply system are very similar to those of the PIG system (1) previously constructed in 1984. The basic physical configuration which is housed in an adjacent room above the ion source area is approximately a mirror image of the PIG layout. A majority of the power supplies, the arc power distribution, safety chain layout, fiberoptic communications, and the computer control system are very similar if not identical in design to previous PIG systems. Several new subsystems, a pulsed arc power supply and a pulsed gas controller, were designed for the duoplasmatron and will be discussed below.

Arc Power Supply

As shown in figure 3, the power supply includes a series-pass actuator, a capacitor bank to provide the high peak currents required by the pulsed load, and a regulator circuit to precisely control the the output current levels. The specifications for this power supply are given in table 1. The utilization of high voltage FET power transistors in the actuator module and small electrolytic capacitors in the energy storage section offer some tantalizing innovations to a very straightforward design.

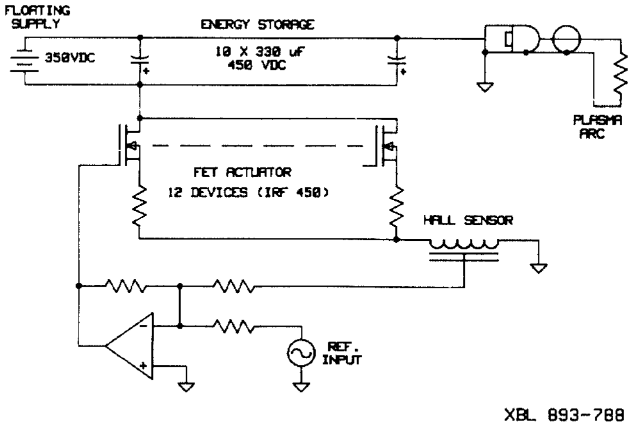

Figure 3. Duoplasmatron Arc Power Supply

1) Pulse width (max)	1.5ms
2) Rise/fall time (max)	20.0 us
3) Rep.rate (max)	2.0 hz
4) Peak current (regulated)	40.0 amps
5) Closed loop bandwidth	350.0 khz
6) Voltage (max)	350.0 volts
7) Min. load (resistive)	8.7 ohms

Table 1

Power supply specifications

An N-channel enhancement mode power MOSFET (IRF450) transistor manufactured by International Rectifier was selected over an equivalent bipolar device for several important reasons. These devices have excellent high frequency response, equivalent if not superior high voltage standoff capabilities, but most importantly they exhibit an absence of secondary breakdown characteristics that severely limit the power capabilities of bipolar devices. The power dissipation of the MOSFET's is only limited by the thermal characteristics of a specific package and heat sink design which results in a smaller and less complex heat sink assembly

To effectively use the FET in a linear application as described, a minor problem must be taken into account. At these voltage and current levels (300 volts @ 1 to 2 amps per device) the much touted self adjusting current sharing capabilities of these devices does not come into play. In addition the gate process parameters allow for fairly wide variations in gate threshold voltages further aggravating the problem of unequal current distribution between devices. The insertion of 1 to 4 ohm resistors in the source lead of each device greatly improves their current sharing capabilities. This fact reduces the total actuator power capability by approximately 5% but still offers a significant advantage over a bipolar assembly.

One of the more efficient devices in terms of size and weight for the storage of electrical energy greater than several joules is the electrolytic capacitor. Unfortunately most large high voltage (1000 uf, 450 VDC) tantalum or aluminum electrolytic capacitors have parasitic resistive and inductive components which not only reduce the overall capacitance as a function of frequency but form a low Q resonant circuit at frequencies between 10 and 100 KHz. Consequently the energy available to the load is reduced and a resonant impedance at a frequency inside the passband (f3db=350 KHz) of the feedback system makes closed loop regulation fairly difficult.

The solution for this particular application required that the total capacitance of 3300 uf be divided into ten 330 uf devices. Examination of the typical impedance vs frequency chart of standard electrolytics clearly demonstrates that the parasitic resonant point for the smaller devices (<500 uf) is considerably higher than that of the larger capacitors (>1000uf). Furthermore these devices were selected from an existing stock of laboratory specified "stacked foil" low Equivalent Series Inductance (ESR) devices. To further enhance the capacitor bank's high frequency performance, several 2.0 uf paper capacitors were added in parallel to the array

Duoplasmatron Source Terminal

A marked similarity exists between the duoplasmatron source terminal and the conservatively designed PIG source terminal located in the adjacent source room. (1) Since the RFQ input energy of 8.4 keV/nucleon required a modest terminal voltage of only 33.5 kV for acceleration of helium 1+ ions, less stringent requirements were demanded in the design of the source room and the placement of the source rack equipment. The hot rack, isolated from ground with four ceramic insulators, supports the arc termination grounding cage as well as housing the mechanical vacuum pump, the gas bottle rack, the pulsed gas valve and and filament power supply electronics. Freon coolant is routed to the source terminal from an external heat exchanger through nylaflow plastic tubing which is very compatible with the required voltage gradient.

Beam Transport and Diagnostic Section.

An overall sketch of the duoplasmatron source and transport section is shown adjacent to the PIG source in figure 4. A single tape wound solenoid magnet, an x-y dipole, and a quadrupole 4-plet are used to transport the beam and match it to the acceptance of the 200 MHz RFQ linac. The beam line is pumped by a 1500 l/sec Welch turbo pump that adequately handles the source gas load of hydrogen or helium. The total beam current is monitored by a beam transformer at the source and by faraday cups located in each of the diagnostic boxes. Beam size and focus is determined with an x-y profile monitor. An aperture restriction currently exists in the straight through section of the 70 degree magnet which presents no difficulty with helium ion beam transport, however a 50% loss in efficiency is noted with 17 keV hydrogen ions.

Ion	**Ion Intensity (particle uA)**	
	Source	**Sta.#3**
H2 1+	2500	600
D2 1+	4100	1300
He 1+	5000	3500

Table 2

The data in table 2 summarizes the operational ion output of the source at the locations listed. Helium ions are generally used for therapy treatment and the quantity of beam shown in the table below will permit acceleration of more than 2E11 particles per pulse of circulating beam in the synchrotron.

References

(1) "Improved Bevatron Local Injector Ion Source Performance" IEEE Trans. Nucl. Sci.,NS-32, No. 5, 1806 (October, 1985).

(2) "Directly Heated Lanthanum Hexaboride, Filaments", K. N. Leung, P. A. Pincosy, and K.W. Ehlers, Rev.Sci.Instrum. 55, 1064 (July, 1984).

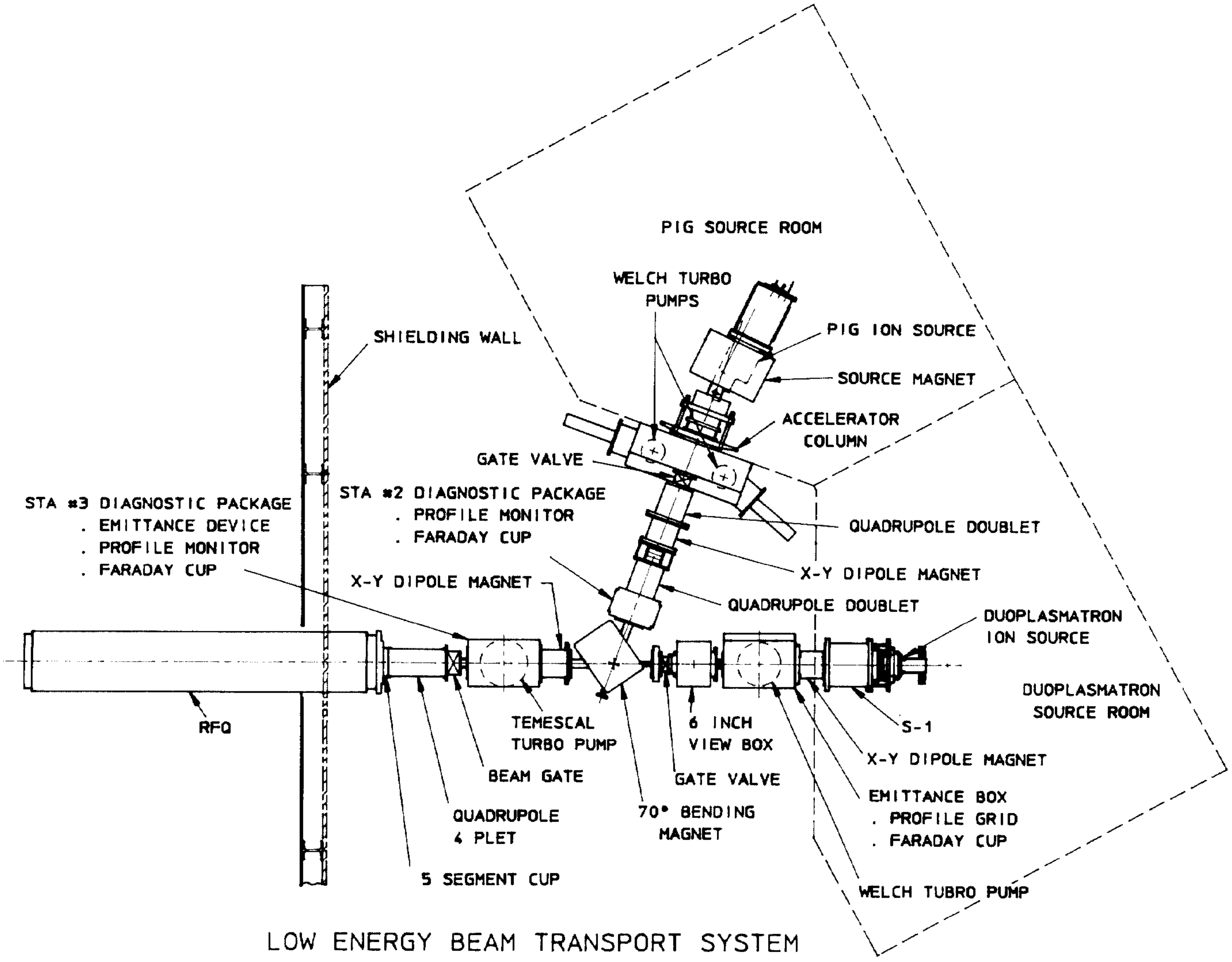

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Figure 4.