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THE BERKELEY 2 MV HEAVY ION FUSION INJECTOR*

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Abstract

This paper is an update on the development of the 500 mA per beam sixteen beam injector being built at LBL. An inductively graded Marx bank provides the acceleration potential on the electrostatic column. A carbon arc source provides the pulsed current for the injector. We report recent results on extracted beam parameters, column performance, the generator performance, and system design changes. The carbon ion beam is diagnosed with Faraday cups and with a double slit emittance measurement systems. Controls for the final machine are also discussed.

Introduction

The machine described in this paper is intended for use with a scaled Induction Linac Systems Experiment which is discussed in several other papers at this conference.(1,2,3,4) The performance requirements dictated by this application are as follows:

Ion- C^+
Ion Energy- 2 MeV
Current per Beam- 340 mA
Normalized Emittance per Beam- 5×10^{-7} π meter- radians
Number of Beams- 16
Pulse Length- 1 μsec
Pulse Flatness- 0.1%

The actual design target for each beam is 500 mA though the matching section of the linac will not be capable of handling such a large current. The overall configuration of the injector is shown in Fig. 1. The pressure vessel is to be filled with a 30% SF_6- 70% N_2 insulating gas mixture at 65 psig. The 2MV generator is an inductively graded Marx generator. The accelerating column is made with 28 inch diameter alumina niobium-brazed modules. Two 18 inch long modules are required for the full 2 MV system.

were made to work for 2500 shots with 5 breakdowns at full charge voltage. The output pulse was approximately critically damped with a rise time (0 to peak) of 30 μsec and a peak output voltage of 512 kV. The voltage was measured by monitoring the current through two 8 kΩ, 500 kV calibrated resistors in series which provide a dummy load for the generator. The reason for using such a slow pulse when only a 1μsec current pulse is needed, is the need to allow voltage equilibration to occur on the column electrodes before beam insertion, and to prevent voltage overshoot caused by stray capacitances between the column and the pressure vessel wall.

Subsequent to these tests, a new set of rings was constructed using stainless steel toroids as coil shields. In the same system, these rings worked without any breakdowns for about 2500 shots in the design gas mix and at full charge voltage.

Most recently, a ten tray subsection of the full generator was constructed to test operation at the 1 MV level. The tray and inductive ring designs were left unchanged. The vessel was filled with 90 psig dry air and the system was operated up to 1.2 MV terminal voltage without breakdown. Soon the system will be fired into an open circuit in order to ring the voltage up to the 2MV region. This will provide some early testing of the high voltage hold off capability in the existing pressure vessel.

Source Development

The source being developed for the injector is a three cathode carbon arc. The operation of the source has been described elsewhere.(5) The plasma from the arc is restrained from filling the extraction gap by means of a planar electrostatic plasma switch which consists of two grids, the downstream grid being biased negatively with respect to the upstream grid. The negative grid defines a planar extraction surface for the ion gun, which prevents transient plasma meniscus effects from distorting the ion optics. The use of three

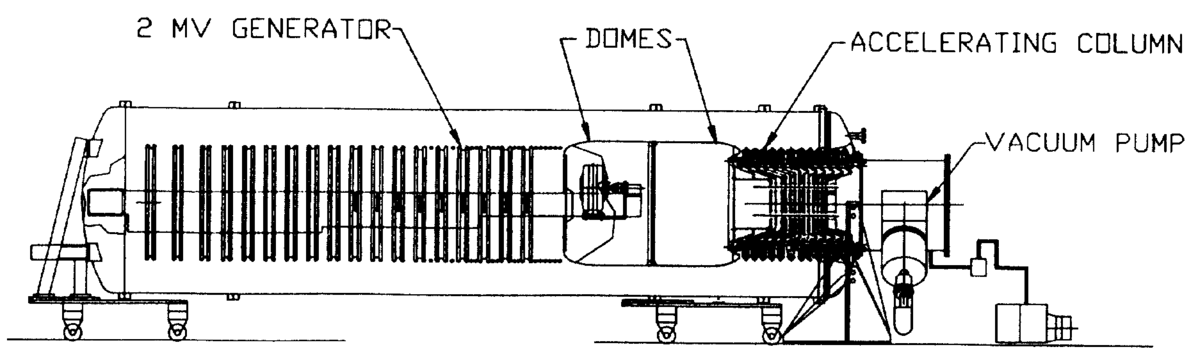

Fig. 1 2 MV Injector System

High Voltage Generator

The high voltage generator uses Marx technology with inductances distributed along the Marx to create a slow rise critically damped pulse. The inductances are 38 inch diameter coils which are shielded for breakdown protection. One inductive ring is located at each tray, as shown in Fig. 1, and provides a self inductance of 17 mh. A four tray (eight stage) subsection of the full eighteen tray system was constructed. Only the first four stages are triggered. A first design of the inductive rings which used aluminum spinnings to shield the 100 turn coils was tried and breakdown problems were encountered above 80% of the design charge voltage of 100 kV per capacitor. The breakdowns were mainly between the shields extending toward the center from opposite ends of a given coil. After considerable effort to refine the assembly of the system, these rings

cathodes is intended to produce a smoothly varying plasma by adding the plasmas from three randomly varying arcs. Streak photographs were taken of the luminosity of the three cathodes to determine whether the cathodes were igniting simultaneously. The cathodes are driven by a common pulse forming network and therefore must be ballasted. Two ballasting circuits were used for these measurements. One was a 4 Ω resistor in series with three 3Ω resistors each of which went to a cathode. The second circuit was three 16.5 Ω resistors in parallel each going to a cathode. Both ballast schemes produced the 5Ω load required by the PFN. The streak photographs showed that the 3- 16.5Ω circuit produced more reliable triggering of the three cathodes and more temporally uniform firing. The maximum delay from the firing of the first arc to the firing of the last arc was 10 μsec. This time is short compared to the normal 40 μsec

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delay used between arc ignition and the firing of the beam extraction voltage pulse. The other circuit was checked because it had been used in another test setup with the source when good emittance data was obtained.(5) The 3-16.5Ω circuit is used for the data which follows.

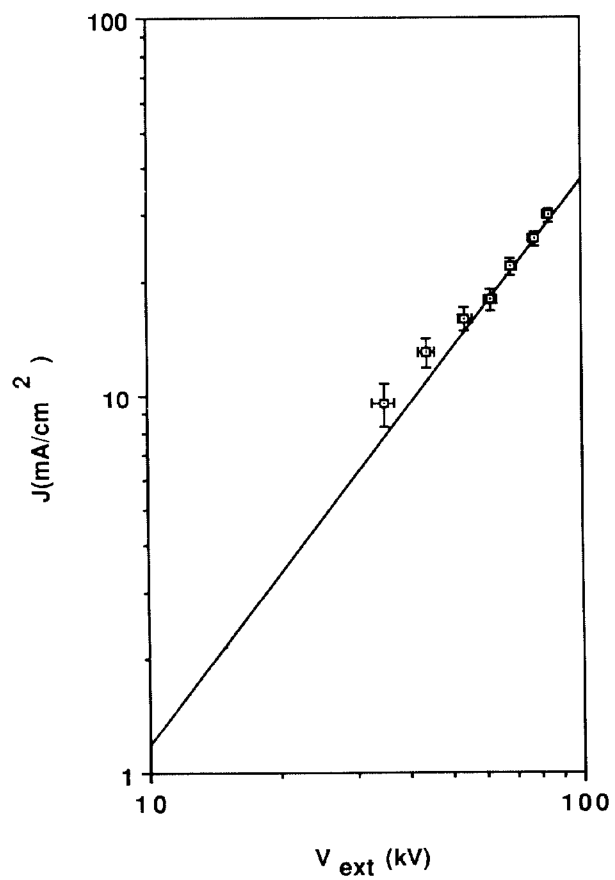

Fig. 2 Current Density From Three Arc Carbon Source at 350 A Arc Current.

The extracted current density from the source as measured with a gridless long Faraday cup is shown in Fig.2. The plasma switch mesh used for these measurements was a 200x200 stainless steel woven grid made of 1.6 mil wires. The geometric transmission of the grid is 46.2%. The theoretical emission curve is for a Child-Langmuir diode 1.29" in width with an 81% transmitting grid in the exit aperture to prevent beam defocussing. The data points are taken at 6 μsec after the start of the 11 μsec extracted pulse. The cup has a .25" diameter aperture and is located at the beam center. The emission surface of the planar extraction gap is 2.0" in diameter while the exit hole containing the 81% transmitting grid is 1" in diameter. The delay between the firing of the arc source and the firing of the extraction voltage pulse is 40 μsec and the plasma switch voltage is -80V. The data points lie quite close to the ideal curve. The current density shows no sign of saturation up to the voltage limits of our test system. The maximum current density obtained was almost 30 mA/ cm^2, which after accounting for the exit grid absorption is equivalent to 37 mA/cm^2, compared to our design current density of 25 mA/ cm^2. The total arc current used in these measurements was 350 A which is the maximum achievable with our pulse generator. It is desirable to keep the arc current, and consequently the arc energy, as low as possible to maximize the life of the source as well as to minimize the size of the arc pulsers needed for the complete injector. Subsequent to the experiments discussed above, we installed an electro-deposited copper mesh into the plasma switch to replace the stainless steel mesh mentioned above. This mesh is 250x250 with 0.6 mil conductor and is not woven. It's transmission is therefore 72.2% or almost 1.6 times as large as the stainless steel used above. It was not possible to get good plasma shutoff with the arc discharge current at 350 A because switch breakdowns started to occur before the plasma was fully shut off, so the discharge current was reduced to 300 A. The extracted current waveforms looked clean and the current density followed the Child-Langmuir slope without evidence of saturation up to 34 mA/cm^2 into the cup. When the arc discharge current was reduced to 250 A, the extracted current pulses became erratic with spikes appearing along the normal waveform trace.

The emittance of the source is measured in the same gun system used above with a double slit technique. The emittance plot for conditions corresponding to those of Fig.2 is shown in Fig. 3. The normalized emittance for this scan is 6.6×10^{-7} π m-radians which is comparable to previously obtained values for a 1" beam.(5)

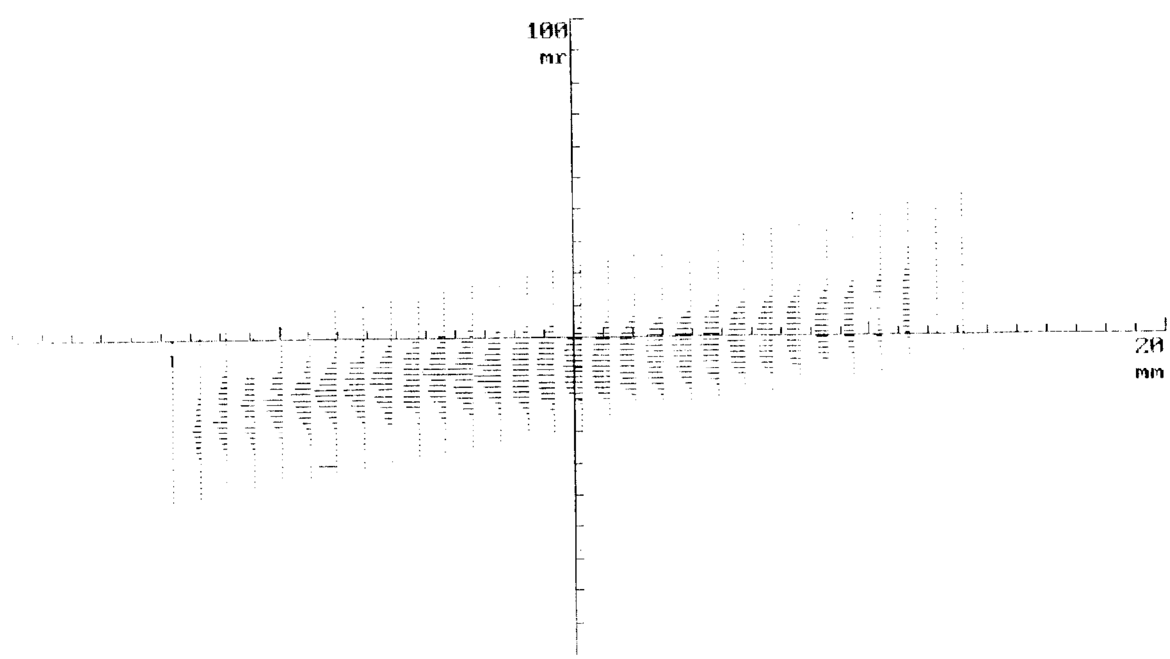

Fig. 3 Emittance Scan for Three Arc Carbon Source at 350 A Arc Current.

This emittance is obtained by drawing an ellipse around the distribution and it correspnds closely to four times the RMS emittance. The extraction voltage was 68kV which puts the extracted current density at 22.5 mA/cm^2 on Fig. 2. There are two odd points in the scan. The first is a zero in the fourth vertical scan which is a true misfire of the extraction voltage pulse. The second is an "out of range" signal in the seventh vertical scan which is attributed to a plasma switch breakdown. Signals from the rest of the shots in the scan were nomally shaped, reflecting the voltage pulse shape. A good scan was obtained using the copper plasma switch mesh mentioned above. The normalized emittance for this scan was 5.5×10^{-7} π m-radians and was taken at 300 A arc current and -80 V plasma switch voltage.

At present the extraction system and the diagnostics have been modified to test 2" beams such as will be required in the injector. Langmuir probes have been constructed to measure the electron temperature and ion density as a function of position and time at the location of the plasma switch grid. This will provide guidance for the optimal design of the source. Another source with three widely separated and independently triggered cathodes has been constructed an will be tested soon.

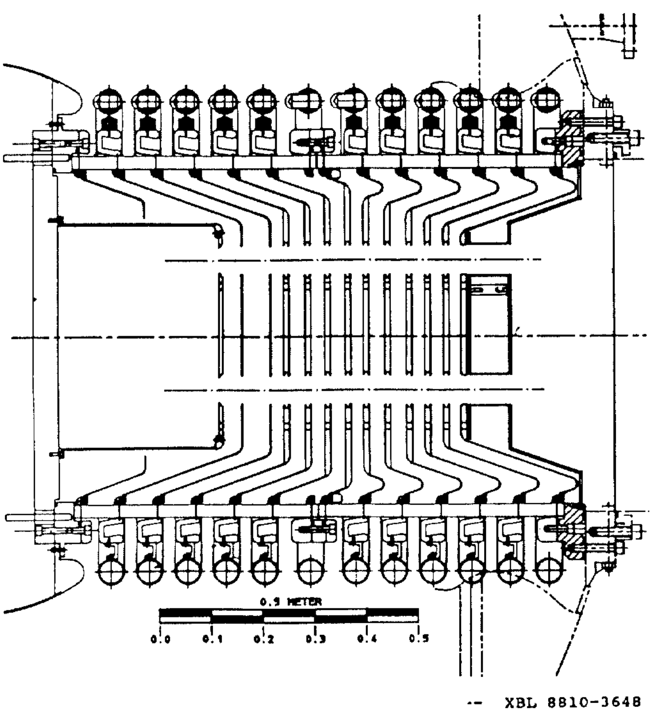

Fig. 4 Acceleration Column Structure.

Acceleration Column

The column for accelerating the beam is shown in Fig.4. The electrodes for the first half of the column are presently being fabricated. Once completed, this half column will be used with the 1 MV generator and with a single, three arc source for 1 MV beam experiments. The electrodes are mounted inside 85% purity alumina brazed insulator modules which have been built and vacuum tested. Voltage grading of the column is accomplished with a double helix liquid (Na_2SO_4 in water) resistor which will provide the proper matching resistance for the inductive Marx so that a critically damped pulse will result. The source will be mounted on the left side of the column and the associated electronics for firing the source will be located inside the high voltage dome partially shown on the left side of Fig. 4. The column focusses the beam by use of a set of aperture lenses formed by the double hole structures shown in the thick plate electrodes. These lenses also inhibit propagation of backstreaming electrons. The first electrode on the left has a grid in the aperture. This grid is the exit of a 9.8mm planar extraction diode. Once the acceleration voltage pulse has reached its peak, the source will be pulsed negatively with respect to this first electrode and the 1μsec current pulse will be injected into the column. The voltage between electrodes is 175kV with the exception of the first gap which is 69.4kV. The overall column length is 58 cm and the beam holes are 56 mm in diameter. At the end of the column is a 3" long cylindrical electron trap which produces a 900V barrier for electrons on axis. The beam exit divergences are -3 mradians for 340 mA and +6.9 mradians for 500mA.

Control System

Control philosophy will follow a highly distributed microprocessor-based architecture. Control implementation will track and make use of the work done by the Advanced Light Source Control group (see ref. 6). Initial elements of control will be largely external to the dome high voltage e.g. monitoring the water load regulating system and dome alternator data (frequency, output voltage). Eventually, status information for the vacuum and interlock systems would be monitored. The operator control will be a 386 based PC. The PC will access a remote microprocessor based controller card (ILC, Intelligent Local Controller) via a RS485 multidrop line. Later, ILC's will be added (at the high voltage level) to monitor and control the dome electronics. One would then for example, control anode pulser voltage level, arc current levels and bias voltages via light links bringing each ILC's data base into the IBM AT. Microsoft windows will be the basic operating environment. Graphics will be generated via Micrografx's Designer package. Control and monitoring will be exercised via ALS control software making use of commercial packages such as Exel. Communications between applications are via Microsoft's DDE (Dynamic Data Exchange) protocol. This control system can be extended later to follow the ALS control system architecture of which this is a subset. See this paper presented by the ALS group to the 1989 PAC conference (ref. 7).

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