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A COMPACT 250-kV INJECTOR SYSTEM FOR PIGMI*

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Summary

A 250-kV proton injector to be used in the development of a linac suitable for medical applications has been constructed. This injector utilizes a spherical Pierce geometry to produce a converging beam. A gas insulated accelerating column is cantilevered on a grounded vacuum system, with a separate high voltage equipment dome connected to a 300-kV Cockcroft-Walton power supply. The injector can be operated locally or remotely, with the remote control accomplished by a microprocessor system linked to a central control minicomputer. This injector has been designed as a low-cost compact system. The design details and the data obtained during initial operation are presented.

Introduction

The National Cancer Institute of the U.S. Department of Health, Education and Welfare is currently supporting a program of accelerator development at the Los Alamos Scientific Laboratory aimed at producing small, inexpensive, and reliable linear accelerators for medical applications. The main goal of this program is to develop a small proton linac suitable as a Pion Generator for Medical Irradiations (PIGMI), although the technology also has neutron generator applications.[1]

Although there are many innovations in this extension of linac technology, the most important with respect to the injector is the use of low-beta accelerating structures in the initial stage of this linac. These structures permit a reduction of the proton injection energy from the conventional 750 keV to 250 keV and thus allows a major savings in the cost and complexity of the injector system. To evaluate the practicality of these new concepts, a 250-keV proton injector has been constructed. This injector consists of a 250-kV accelerating column mounted on a grounded vacuum system, a conventional duoplasmatron ion source, and a separate high voltage equipment dome located inside an interlocked high voltage safety cage.

Injector Description

High Voltage Generator

The source of high voltage is a commercial Cockcroft-Walton power supply with a maximum output of 300-kV at 1.4 mA. The solid state voltage multiplier stack is mounted under the equipment dome as seen in Fig. 1. The stack is driven by a 20-kV, 50-kHz power oscillator mounted in a rack just outside the high voltage cage. The power supply is protected by over-voltage and over-current limiting features; remote voltage programming and safety interlocks are also provided.

The power needed to operate the equipment in the high voltage dome is supplied by a 5-kVA, 300-kV isolation transformer. This commercial isolation transformer has a modified polyethylene output insulator and uses unshielded RG-19U cables to carry the a.c. power into the dome.

High Voltage Dome and Equipment

The high voltage equipment dome consists of three standard rack cabinets mounted on 8 in. PVC tubing. An aluminum place is bolted across the top of the two support structures. The Cockcroft-Walton voltage multiplier stack is mounted between these two structures with the top ring of the stack in contact with the aluminum plate. The equipment racks are mounted on this plate. Corona rings have been formed with 3-in. aluminum tubing around the top and bottom edge of the cabinets. This shielding is adequate to prevent corona at 300 kV.

The equipment dome is located approximately in the center of a high voltage safety cage 9-feet wide and 16-feet long, with a minimum clearance of 3 feet. The isolation transformer leads enter one end of the dome through polethylene bushings. On the other end of the dome a 4-in. split aluminum tube carries the gas, power and cooling lines from the dome to the ion source, and accelerating column. The safety cage door is interlocked to the high voltage power supply.

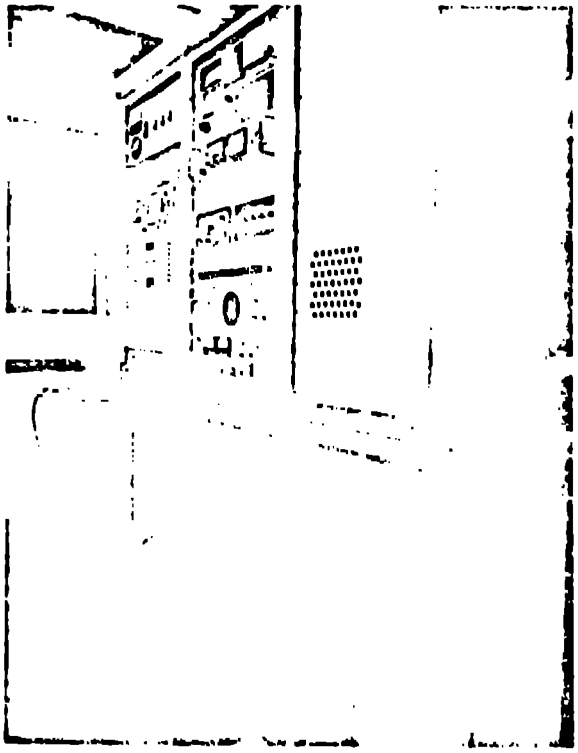

Fig. 1. High voltage equipment dome.

The input power for the dome equipment is brought from the isolation transformer into an a.c. distribution panel. Located in the cabinet with the distribution panel is the microprocessor system. This system consists of a microprocessor crate, an equipment interface chassis, and a fiber optic interface panel. This microprocessor is connected through the fiber optic interface panel to another microprocessor at ground potential which is interfaced with the central control mini-computer. A description of the complete PIGMI accelerator control system is discussed elsewhere in this conference.[2] A four-channel oscilloscope is also located in this cabinet to monitor several analog signals in the dome, but during accelerator operation these signals will be transmitted to a remote grounded oscilloscope

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via separate linear fiber optic channels in the fiber optic interface panel.

The middle cabinet in the equipment dome contains all the electronic equipment necessary to operate the ion source. Basically, this equipment consists of six power supplies to operate the duoplasmatron, one power supply for control circuits, and a transistor arc pulse modulator. A flowmeter gauge for the hydrogen gas system and the Pirani pressure gauge readout for the arc chamber are also located in this cabinet.

The last cabinet in the dome houses the hydrogen gas system and the ion source cooling water system. The hydrogen gas system consists of a small hydrogen bottle, a palladium leak, a hydrogen flow transducer and a pressure regulator connected to a gas manifold. The ion source cooling system is a small closed cycle system which uses a submersible vane pump, a two liter polyethelene reservoir, and a 19,000 BTU/hr. automotive heater radiator with a 24 V fan. The entire cooling system occupies less than two cubic feet. All the lines from the dome to the ion source can be removed easily to allow full access to the ion source and column.

Vacuum System

The accelerating column is cantilevered on a grounded vacuum manifoid that forms part of the high voltage cage. The pumping for this system is provided by a 550-ℓ/s magnetic bearing turbomolecular pump. It was used to minimize the possibility of oil vapor contamination in the high voltage region. This pump maintains a base pressure of $1 \times 10^{-}$ torr in the column and operates at $2 \times 10^{-}$[illegible] torr with a hydrogen gas flow of 1.5 atm cc/min. The last aperture in the accelerating column has been mounted onto the vacuum manifold to minimize the gas flow from the column into the beam line and to maximize the pumping of gas in the interelectrode region.

Accelerating Column and Ion Source

The accelerating column is constructed of eight 15.25-in. o.d. x 13.75-in. i.d. alumina rings bonded to 0.020-in. thick titanium washers, with a large stainless steel flange mounted on each end. This column was constructed at LAMPF for the prototype H^+ injector, with the titanium washers bonded to the ceramic with polycarbonate.[7] The stainless steel flanges have been modified and bonded to the ceramic with Torr-Seal for this injector. The column is surrounded by a lucite jacket which is also cantilevered from the vacuum manifold. This jacket contains the SF_6 insulating gas and can be filled to a pressure of 3 psig with no stress on the column because of a sliding radial O-ring seal.

The voltage dividing resistors and the spark gaps are located inside the insulating gas, and the feedthrough to the extractor electrode is mounted through the end plate of the jacket. The resistor string is made up of small 50 M carbon wound ceramic resistors, as seen in Fig. 2. The total resistance for the voltage dividing network is 1500 M , giving a column resistor current of 157 μA, approximately the average beam current through the column. The spark gaps on the column have a fixed gap, but the firing voltage can be adjusted by changing the SF_6 gas pressure in the insulating jacket.

The ion source and electrode configuration inside the column is shown in Fig. 3. The re-entrant design is required because of the high current needed from the injector. The ion source is a conventional duoplasmatron which was built in the development of the LAMPF H^+ injector. Water cooling is needed only for the intermediate electrode and arc magnet coils in this application. The filament is a standard bifilar oxide-coated nickel screen cathode, and the plasma aperture mounted on the ion source housing uses a 0.025 in. aperture. The Pierce anode is mounted on the face of the source and is isolated so that it can be biased with respect to the source.

Fig. 2. Accelerating column.

The first two accelerating electrodes in the column are mounted on re-entrant cans that can be positioned with the mounts that attach them to the titanium washers in the column. The electrodes are constructed of 6Al-4V titanium and are riveted into stainless steel cans that have holes to provide pumping in the interelectrode regions. The last electrode, at ground potential, is also constructed from titanium but is mounted into the stainless steel vacuum manifoid as stated earlier. The alignment of these electrodes and the ion source is performed optically with a radial accuracy of ±0.005 inch.

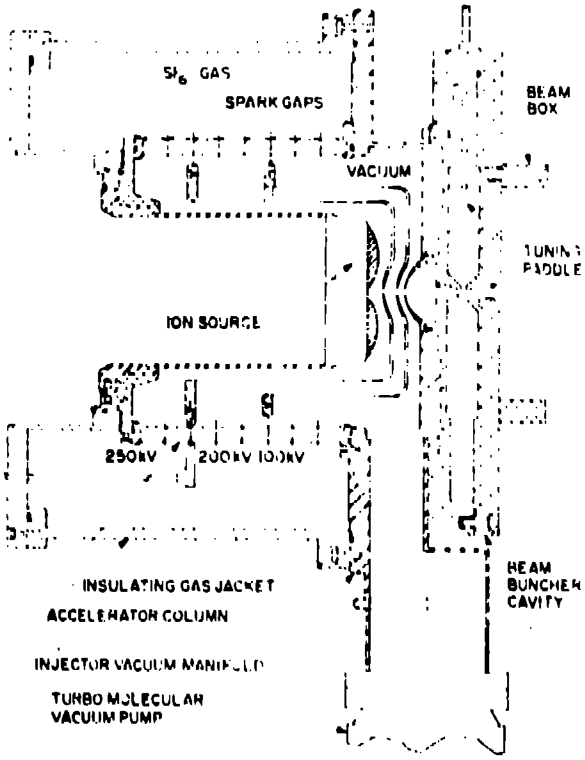

Fig. 3. Cutaway view of the accelerating column.

Electrode Design

The column electrodes were designed to give the ion beam extracted from the source a radial convergence of two in order to make the beam small enough to pass through the 5-mm diameter apertures in the buncher. The calculations of Langmuir and Blodgett[4] were used to determine the potential distribution along the edge of a 50-mA beam of protons extracted from an 8-mm diameter plasma surface in a spherically converging geometry. The solution of LaPlace's equation in spherical coordinates was used to obtain the equipotentials outside the beam at 0, 100, 200, and 250 kV. Electrodes were then placed at these equipotential surfaces. The solution for the Pierce anode is shown in Fig. 3. The shape determined for the other electrodes was essentially spherical, so these electrodes were made with spherical surfaces.

After the electrode shapes had been determined by this analytical calculation, this accelerating system was studied with the ion beam code SNOW. This space-charge particle code solves the Poisson-Vlasov equation in the plasma region. The trajectories of the particles extracted from the plasma are then calculated through the accelerating system. A uniform plasma with zero emittance was assumed and the results are shown in Fig. 4. This calculation shows that the 50-mA beam converges to a 3-mm diameter beam at 250 kV with the waist near the desired position beyond the exit aperture of the column.

Experimental Results

The high voltage power supply and equipment dome have operated at 300 kV with no corona from the dome or sparking along the support legs. The spark gaps were found to break down in air only a few percent below the design breakdown voltage. With SF gas in the insulating jacket the column conditioned to 270 kV with little difficulty and with normal operation of the resistor string and spark gaps. The entire injector system has been tested at 160 kV, being limited by the high voltage stand-off in the original isolation transformer. A beam of 24 mAp current was obtained with an extraction voltage of 32 kV, yielding a perveance for this extraction system of 4.2 x 10^{-} [illegible] A/V$^{3/2}$, essentially that measured in the initial measurement of the extraction system on a test stand, where 48 mAp current was obtained with 50 kV. The beam extracted in both tests was found to be of good quality with no indication of non-laminarity.

However, during a recent inspection of the column it was found that beam had been impinging on the edge of the electrode apertures. Calculations using realistic plasma conditions revealed that a non-uniform plasma density and the finite transverse temperature of the ions would account for beam impingement on these electrodes. The original design of the electrodes had ignored these conditions and the electrode apertures were set at the edge of the ideal beam envelope. The diameter of all the electrode apertures was then enlarged by 1 mm and the system was realigned. The system will be tested at 250 kV with the new 300 kV isolation transformer.

Conclusion

The 250 kV injector system built for the PIGMI pro[illegible]e study at Los Alamos Scientific Laboratory, incor[illegible]s several new features to achieve a compact, rel[illegible] inexpensive system. The vacuum pumping is [illegible] at ground potential and the accelerating column i[illegible]ated separately from the high voltage equipment dom[illegible]. A small high voltage power supply and equipment dome, a compact cooling and gas system, and commercially available power supplies are used to make the injector design simple and to keep the system cost down.

The accelerating system utilizes a re-entrant spherically convergent Pierce geometry to achieve a small dense beam at the exit of the column. The re-entrant ion source and electrodes are positioned such that there is good pumping in the interelectrode region; the electrodes can be adjusted for proper alignment. The accelerating column uses a simple spark gap and voltage divider arrangement within the insulating gas. This high voltage design for the column and the dome, although very simple, has proven to be very reliable.

Finally, even though the system has not yet been tested at the full design voltage, initial data obtained with the injector has shown that the converging beam design works very well and that the required current can be extracted and focussed from this accelerating system.

Acknowledgements

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Fig. 4. Accelerating column geometry showing calculated equipotentials and proton beam envelope.