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DESIGN STATUS OF HEAVY ION INJECTOR PROGRAM

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Abstract

Design and development of a sixteen beam, heavy ion injector is in progress at Los Alamos National Laboratory (LANL) to demonstrate the injector technology for the High Temperature Experiment (HTE) proposed by Lawrence Berkeley Laboratory. The injector design provides for individual ion sources mounted to a support plate defining the sixteen beam array. The beamlets are electrostatically accelerated through a series of electrodes inside an evacuated (10^{-7} torr) high voltage (HV) accelerating column. The column consists of two 28-inch diameter insulator modules made of 85 percent Al_2O_3 ceramic rings brazed to niobium feedthrough rings to which the electrodes are mechanically attached. Field shaping is used to minimize electron avalanche induced flashover along the inside surface of the ceramic rings. The column is self-supporting and is cantilevered from one end of the containment vessel. A brazed assembly was chosen to provide the required bond strength and high vacuum capability. The HV pulsed power supply is a 2MV Marx generator cantilevered from the opposite end of the containment vessel. The stainless steel pressure vessel (PV) contains a 65 psig mixture of SF_6(30%) and nitrogen (70%) to provide the electrical insulation.

Introduction

A Heavy Ion Injector program is in progress at Los Alamos National Laboratory to develop a prototype injector for the Heavy Ion Fusion program. Figure 1 shows the overall injector design. The basic design incorporates a 2 MV Marx cantilevered inside one end of the pressure vessel. The accelerating column is cantilevered from the opposite end with the HV domes located between the Marx and the accelerating column. A 15 kVA motor driven alternator and transformer is located inside the HV domes with other electrical equipment used to power the sixteen beam sources located at the 2 MV end of the column.

The design concept utilizes individual ion sources spaced on a sixteen beam array to generate each beamlet. The beamlets are electrostatically accelerated through a series of electrodes inside an evacuated insulating column which will operate at 10^{-7} torr. The column will be surrounded by high pressure gas (65 psig, 30% SF_6, 70% N_2) for electrical insulation. The high voltage pulsed Marx generator is also in the high pressure gas for voltage hold off between the capacitor trays. A laser triggered diverter switch will be used to end the Marx voltage pulse after the ion beams have been extracted.

The accelerating column is made up of two 18.6-inch long vacuum brazed ceramic/niobium modules bolted together. The ceramic chosen was Coors AD-85 (85% alumina) since this was the highest alumina content ceramic ring that could be pressed in the 28-inch OD size required. Figure 2 shows the column with its HV dome and other incidental hardware. The assembled column weighs approximately 1625 lb and

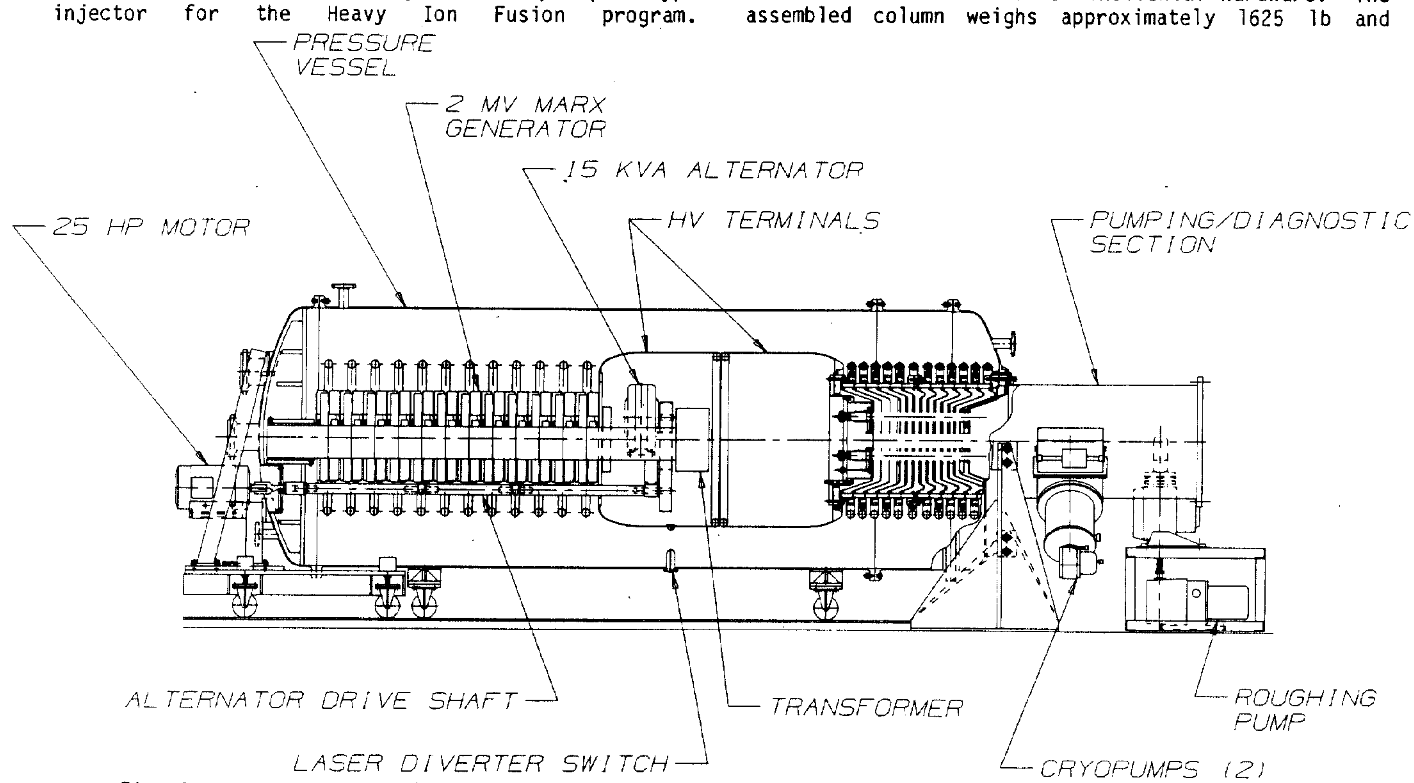

Fig. 1. HEAVY ION INJECTOR DESIGN CONCEPT

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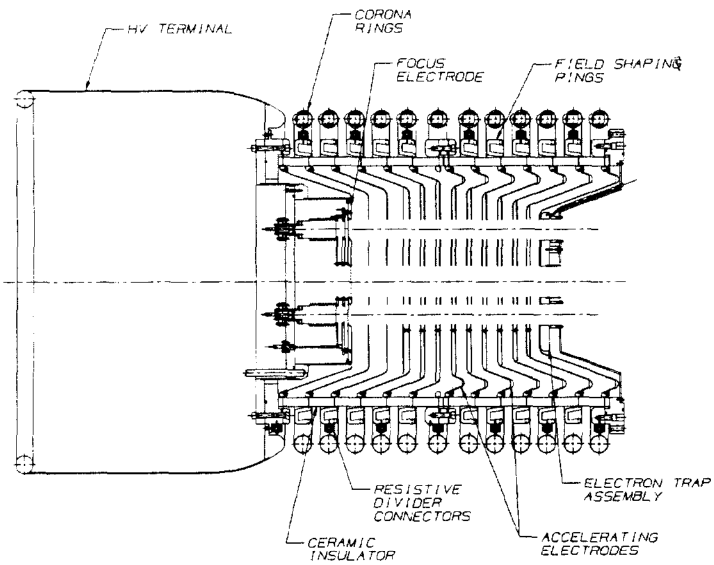

Fig. 2. HEAVY ION INJECTOR ACCELERATING COLUMN

requires an assembly with high strength braze joints to support the cantilevered load. The multiple beam injector design parameters are:

Ion Energy	2 MeV
No. of Ion Beams	16
Current/Beam	150-300mA
Normalized Emittance/Beam	4×10^{-7} Rad-meters
Ion Species	A~23-27
Beamlet Radius	17 mm
Pulse length	6 μsec
Repetition rate	5/minute

Discussion

Ion Optics

The column ion optics have been analyzed using the E-GUN code[1]. The analysis provided the electrode shapes and spacing to establish the required beam emittance and divergence. Analysis is continuing to refine all aspects of the ion optics.

Ion Source

The present plan is to use an aluminum, Al^+, spark discharge ion source for the initial operational goal. Ion source experiments[2] are in progress to develop this primary source as well as a heated potassium zeolite source and a pulsed neon plasma source.

Accelerating Column

The 2 MV accelerating column consists of two metal-bonded ceramic modules, internal electrodes, external field shaping rings and corona rings. It supports the high voltage terminal which houses equipment for the ion source located by reentrant geometry inside the accelerating tube. The column is cantilever supported horizontally but unlike other accelerators it does not have a separate support column to support the accelerating tube. Instead, the accelerating tube itself supports all the other parts of the column. This is feasible in this case because of the large 28-inch OD ceramics required to accommodate the 16 beamlets and the resulting large moment of inertia reduces deflection and stress to low levels. Elimination of the separate support column results in a dramatic reduction of effort required and results in a much cleaner, simpler electrostatic design.

The accelerating tube consists of two 1 MV modules each with six ceramics (28-inch OD x 26-inch ID x 2.9-inch long) metal bonded with Ticusil (titanium copper silver) foil to 0.030-inch thick niobium grading rings between the ceramics. There are ceramic back up rings bonded at each end to minimize stress on the ceramic from the supporting niobium flanges. The assembled column with external grading rings and internal electrodes weighs 1300 lb. The high voltage terminal, ion sources, and associated equipment inside add 325 lb for a total cantilevered column weight of 1625 lb.

Only alumina ceramics were considered for fabrication of the column because they have the highest tensile strength. Tensile stresses are considered the only potential failure mode of the metal bonded ceramic since the compressive strength of alumina ceramics is an order of magnitude higher than the tensile strength. The largest alumina ceramic ring available is 28-inch OD of 85 percent alumina. The expected tensile strength of this large ring is about 11,000 psi. This is comparable to the tensile strength of the Ticusil brazing alloy which will be used to bond the ceramic to the thin rings of niobium.

Pre-loaded stress relief flanges located at both ends of each 1 MV module provide the necessary flexibility for mounting the column to the pressure vessel. The pre-load will prevent any appreciable sag in the column, thereby avoiding misalignment of electrode apertures. The pre-load is obtained by elastically deforming the thin niobium rings at the ends of the modules, thus providing the force to hold the column against the pressure vessel support flange.

High voltage grading of the accelerating column is provided by conductive water in plastic tubing which spirals one-half turn between each section. This produces 175 kV across each of the 2.9-inch long ceramic rings except for the first gap which has 75kV. The water line continues into the high voltage terminals for cooling of equipment and then spirals down the Marx generator to ground potential where the water is chilled before recirculation.

High voltage breakdown inside the accelerating tube will be minimized by careful design that concentrates on eliminating the causes of electron avalanche induced flashover along the inside ceramic wall. The electric field will be shaped to direct electrons away from the wall to avoid electron multiplication. This concept is shown in Figure 3

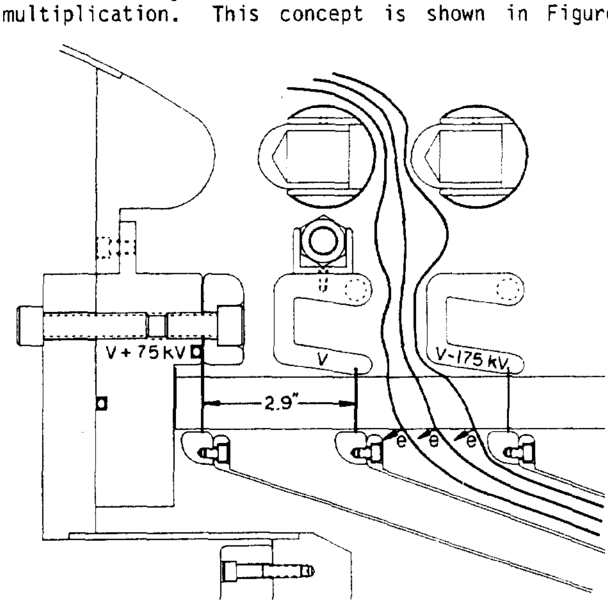

Fig. 3. ASYMMETRIC POSITIONING OF FIELD SHAPING RINGS USED TO DIRECT ELECTRONS AWAY FROM THE INNER CERAMIC WALL AND PREVENT ELECTRON AVALANCHE INDUCED FLASHOVER

with force vectors shown for electrons on the equipotential lines. The negative triple junction at the ceramic-metal-vacuum interface will also be shielded as shown to reduce electron emission from that sensitive region. In addition, there will be an electron trap on each of the 16 beam apertures and the center vacuum pump-out hole to prevent backstreaming electrons from entering the accelerating tube.

Pressure Vessel

The pressure vessel is 304L stainless steel, 64-inch diameter, 3/8-inch wall, 140-inch long, designed for vacuum capability, which also provides a 185 psig internal pressure capability. Although the vessel is not planned for vacuum operation, an inadvertent pumpdown could occur without vessel damage. The anticiapted working pressure is 65 psig for a nitrogen-sulfur hexafluoride insulating gas mix or approximately 100 psig if nitrogen is used.

The assembly that supports the cantilevered Marx generator will have the capability to roll back for easy removal of the Marx assembly. This will provide easy assembly and maintenance of the Marx unit. Also, the cylindrical vessel can be rolled back to provide access to the cantilevered HV accelerating column for assembly and maintenance. The head to which the cantilevered accelerating column is attached will be hard mounted to the floor.

Pulsed Power Supply

A Marx generator has been chosen to provide the HV power to the injector. Other options (pulse transformer, induction modules) were considered but are less desirable because of the cost, although the use of induction modules to power an "electrostatic" column could have advantages in pulse shaping and anode heater power isolation.

The Marx is designed to compensate for the voltage droop due to the charge drawn off the capacitors by the load current and the shunt charging resistors. This is done by the first two capacitors, which are charged negative. The main Marx has extra voltage to compensate for the negative stages. As the voltage in the positive stages droops, the negative stage voltage droops the same amount. Using this technique, the beam voltage can be kept flat to 0.1 percent.

The Marx generator will use lightweight plastic cased capacitors, rated at 100 kV with 0.06 μF capacitance. Two stages of the Marx will be mounted on a 6-inch wide molded plastic tray providing 0.2MV/tray. The twelve trays will rest on two cantilevered insulating beams made of phenolic impregnated densified wood laminate.

A diverter switch is required to end the Marx voltage pulse. Experiments are in progress using a low energy KrF laser to determine the required diverter electrode spacing to provide reliable laser triggering necessary to divert the Marx pulse at the end of the ion beam pulse length.

To provide flexibility and precise control of the ion beam extraction, a technique is being considered whereby the ion source grid can be pulsed separately. This would allow the column voltage to be pulsed on and any oscillations to damp out without a beam present. The beam would then be turned on and accelerated in the column. At the end of the pulse, the beam would be turned off by chopping off the ion source grid voltage while leaving the column voltage on, thus accelerating the tail of the beam to full voltage. A small high voltage pulse generator inside the high voltage terminal will apply the appropriate high voltage pulse to the ion source grid with respect to the extractor electrode. The charging and triggering can be controlled via fiber optic links. Charging power will be derived from the alternator inside the HV terminal used to power the ion sources.

Vacuum System

The vacuum system will be attached to the transition section as shown by the Figure 1 assembly drawing. The vacuum system consists of a roughing pump/blower combination providing 27 cfm (13 l/s) capacity down to 20 torr. At this point the blower boosts pumping speed to 100 cfm (47 l/s) down to a pressure of 1 micron. Two 12-inch cryopumps will be used for low pressure operation to maintain the HV accelerating column and diagnostic section at the 1 x 10^{-7} torr range as required for beam extraction and transport.

Ion Source Power

The ion source power supply system will consist of a two-pole induction motor, 25 hp, 3-phase, 1750 rpm with a magnetic motor starter. The motor will drive an acrylic shaft mounted inside the Marx corona rings with bearing support blocks mounted from the Marx support beams. The shaft will drive an alternator modified to provide an output of 7.5 kVA at 400 hz, 115/200V (nominal), at 1750 rpm. The alternator can also operate at 3500 rpm to provide 15 kVA output if additional power is needed to operate different source types.

Instrumentation and Controls

An instrumentation and control system is presently being developed to provide functional control and information readout of all operating parameters required.

Conclusions

The design of many of the Heavy Ion Injector components, i.e., pressure vessel and support structures, Marx assembly, accelerating column, and vacuum systems has progressed to the final design stage with detailing in progress on these subsystems. Other design areas, i.e., ion source, electrical subsystems, laser diverter switch, and instrumentation and controls are still in the testing and preliminary design stages.

Fabrication of the pressure vessel and support structures will begin in late FY-85. Brazing of the HV insulator modules is in progress. Complete fabrication and assembly is expected to occur in FY-86 with initial testing to begin late in FY-86.

Acknowledgements

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