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November 1985

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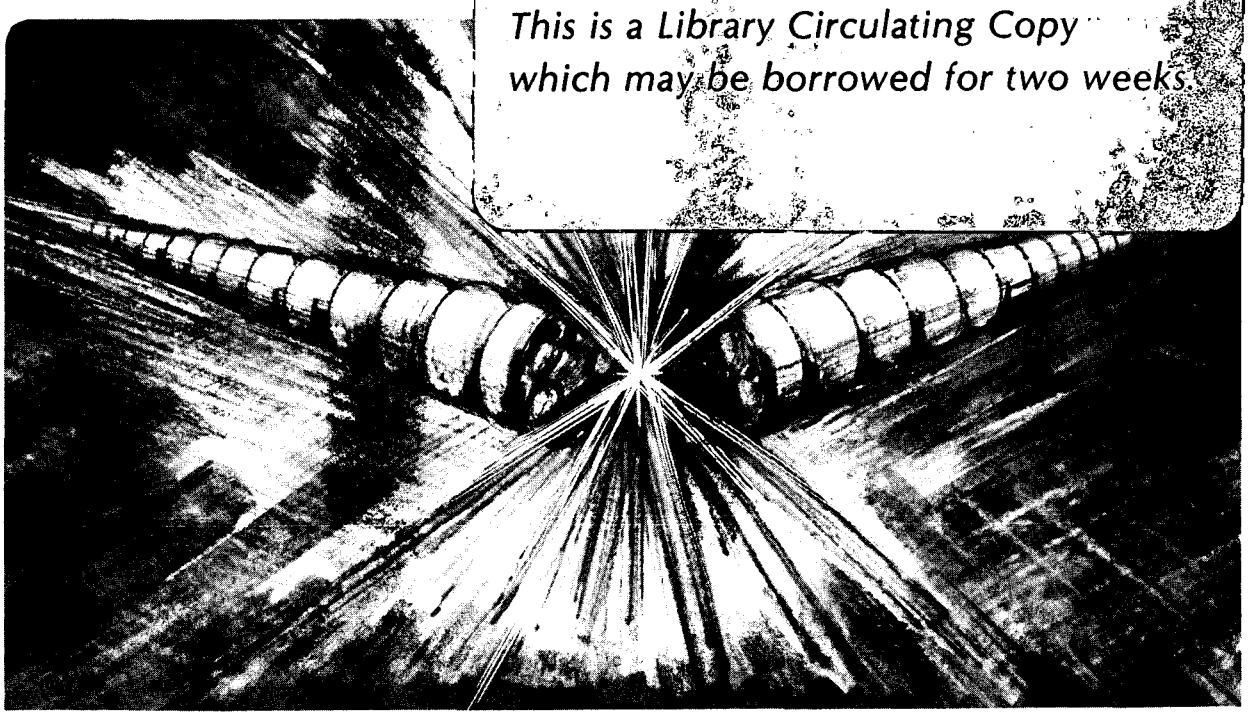

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MECHANICAL DESIGN AND FABRICATION OF THE TRANSVERSE FIELD FOCUSING (TFF) MATCHING/PUMPING SECTION FOR NEGATIVE ION BASED NEUTRAL BEAM SYSTEMS*

P. Purgalis, O.A. Anderson, G.W. Koehler, Y. Maruyama, C.A. Matuk,
H.M. Owren, J.A. Paterson and A.H. Wandesforde
Lawrence Berkeley Laboratory
University of Califonia
Berkeley, CA 94720

Introduction

A negative ion based neutral beam injection system is under development as proof-of-principle demonstration of a radiation-hardened beamline.[1] The beamline consists of a source,[2] a pre-accelerator, a matching/pumping (M/P) section, and an accelerator.[3] A plan view of the beamline is shown in Fig. 1. The function of the M/P section is to provide vacuum pumping, to remove electrons, to provide beam edge confinement, to compress the beam thickness to match the requirements of the accelerator and to transport the 1A, 80 keV, 25 cm high H^-, ribbon beam to the accelerator entrance. Details of the design and fabrication of the M/P section are presented.

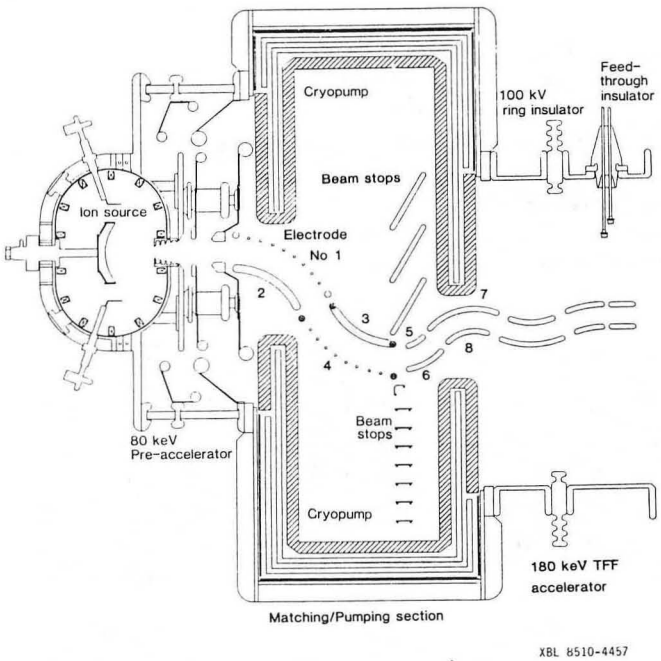

Fig. 1 Plan view of the negative ion 180 keV TFF system.

Description

The M/P section is the center module shown in Fig. 1. Eight separate, high voltage, electrodes form an "S" shaped beam path. The first two outer arc electrodes consist of water cooled molybdenum tubes while the remaining electrodes are water cooled copper plates. The open and closed electrode arrangement together with baffles provides differential cryopumping. The cryopump assemblies cover the housing walls and are protected from excesive heat loads by water cooled beam stops. Monte Carlo calculations show that the cryopumps decrease the gas pressure from 10^{-3} Torr at the source to 4.7×10^{-6} Torr at the accelerator entrance in an axial distance of 54 cm.

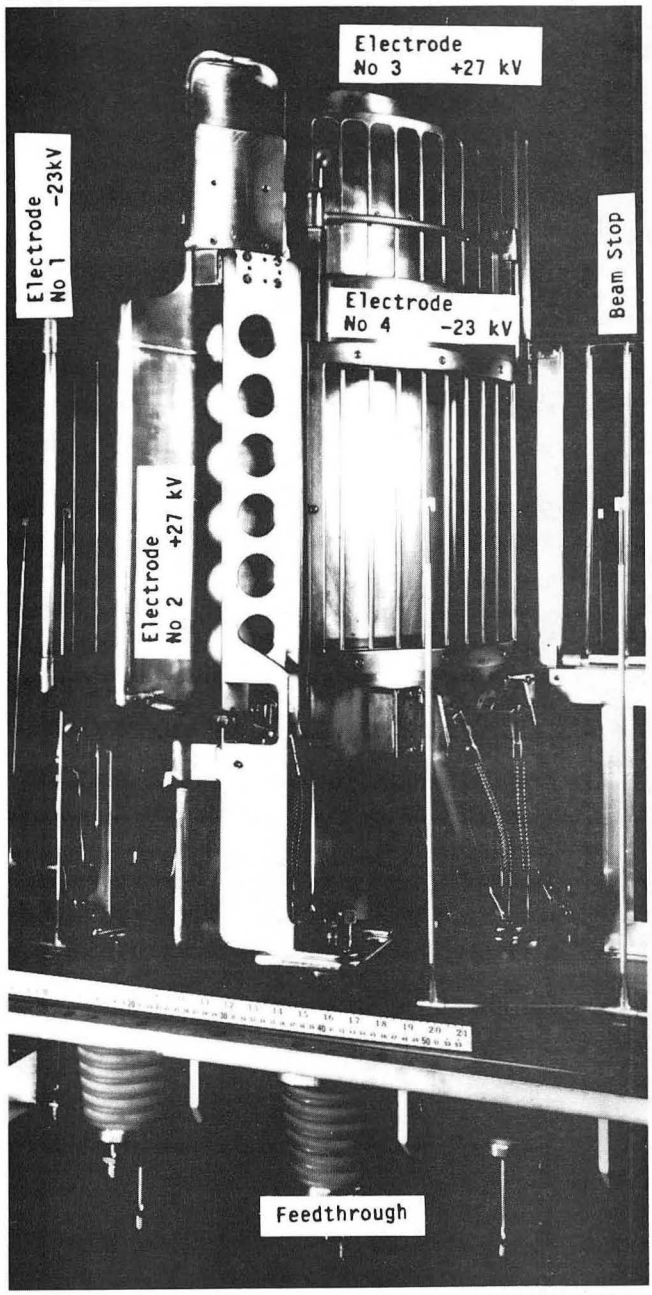

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Fig. 2 First four electrodes of M/P section.

The electrons are removed by the electron trap consisting of electrodes No. 3 and 4. Permanent magnets are located in water cooled tubes at the entrance

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and exit of these electrodes. The magnetic field deflects the electrons into electrode No. 3. The heavier negative ions are deflected only slightly and the exit magnets straighten out their trajectories.

The beam edge confinement and thickness compression is accomplished by the curvature and face contour of the electrodes.[1]

The M/P section is enclosed in a 54 cm x 138 cm x 96 cm high housing. The cryopump assemblies are suspended from the housing walls. The other components are mounted on the housing floor plate as shown in Fig. 2. Each electrode is supported from a single cast epoxy feedthrough that provides electrical isolation, supplies the cooling water and the high voltage connection. The voltages shown in the figure are for the test of the M/P section. When the accelerator is added, the housing will be at -100 kV and all the voltages will decrease by that amount.

Design Heat Loads

The sources of heating are from neutrals due to stripped H^-, from secondary electrons caused by impingement of neutrals, and from electrons in the beam that are deflected to No. 3 electrode.

The design and calculated heat loads, with and without cryopanels, are shown in Fig. 3. The higher calculated heat loads are for the arrangement shown in Fig. 4. The M/P section was tested in this arrangement, without the cryopanels and accelerator.

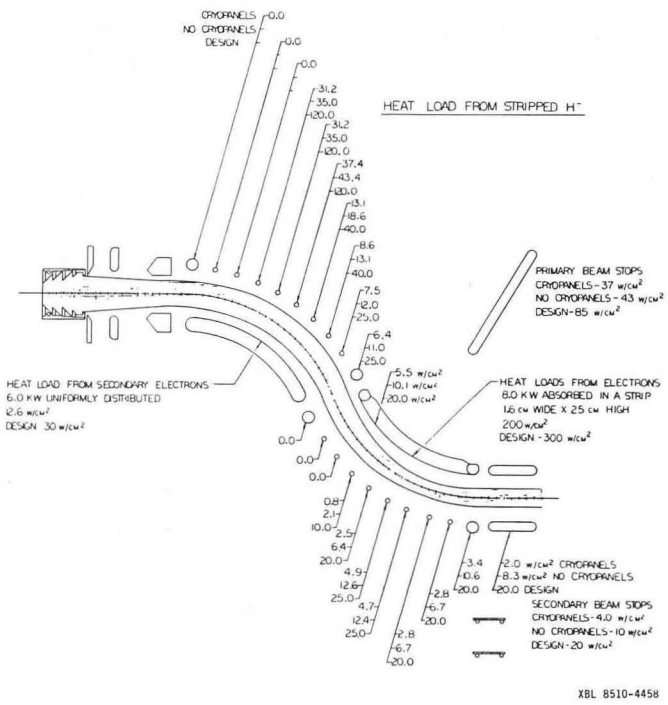

Fig. 3. Calculated and design heat loads

The design procedure was to calculate the particle density distribution along the beam path using a two dimensional Monte Carlo computer code.[4] Figure 4 is a computer plot of the surfaces used in the Monte Carlo calculation. The beam stops were positioned to protect the cryopanels and to minimize interference with pumping. From the particle density distribution the beam loss, due to stripping of H^-, was calculated at .5 cm increments along the beam path.[5] The stripped particles from each increment continue in a straight line, tangent to the beam path, and impinge on the nearest surface.

The heat load on electrode No. 2 and 3, from secondary electrons, was estimated from the neutrals hitting electrode No. 1 and 4, and using an emission coefficient of two.

Approximately 10% of the beam current is carried by electrons. The area on electrode No. 3 that these electrons impinge on was determined from electron trajectory calculations.[6]

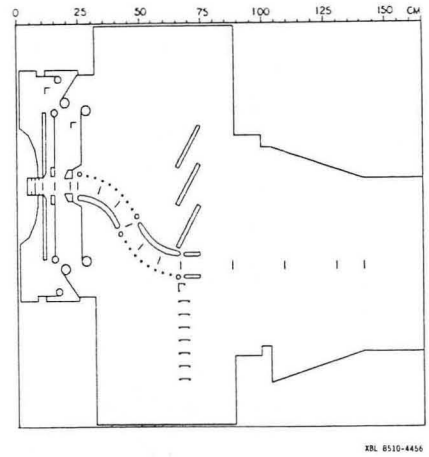

Fig. 4. Plan view of M/P section as tested.

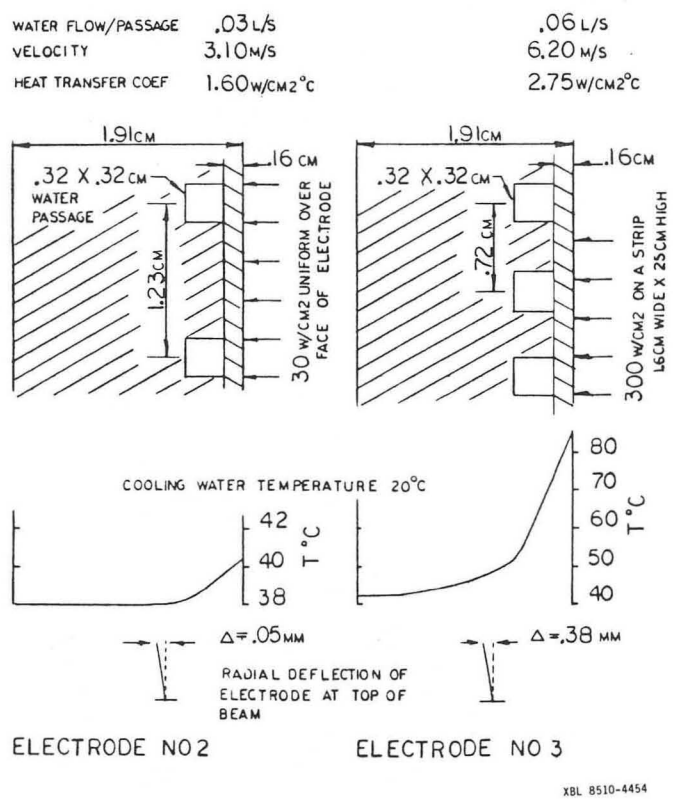

Fig. 5. Solid electrode cooling passage arrangement, temperature profile, and deflection.

Based on the design heat load cooling water requirements were selected to keep electrode deflection low. The calculated temperature profiles and deflections for the No. 2 and 3 electrodes are

shown in Fig. 5. The calculations were made using a finite element computer code. Actual deflections will be less than shown since the stiffness of the stainless steel bracket was not included in the calculations.

The calculated temperature distribution for a molybdenum tube of electrode No. 1 is shown in Fig. 6. The electrode deflection was estimated from the moments of the individual tubes.

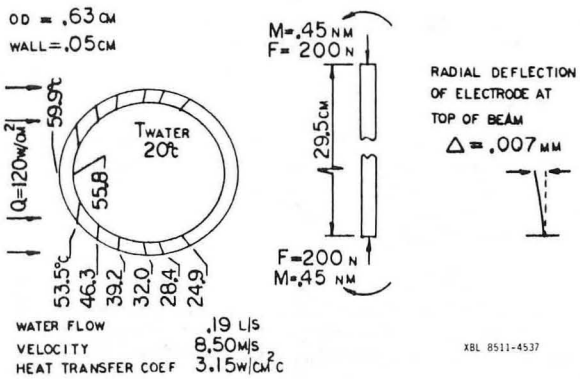

Fig. 6. Temperature distribution and deflection for No. 1 electrode.

Electrode Fabrication

At the present, electrodes No. 1 through 4 have been fabricated. All the copper electrode parts were machined from plates that were rolled into cylinders. The cylinders were then turned to the required inside and outside diameters and the cooling water passages machined. The cylinders were then annealed and cut into the required segments before the final machining was done.

The two open electrodes consist of molybdenum tubes brazed to copper reservoirs. Fig. 7 shows the No. 1 electrode assembled on the brazing fixture. Brazing was a two step process, the molybdenum tubes were brazed to the reservoir lids and then the tube assembly was brazed to the reservoirs.

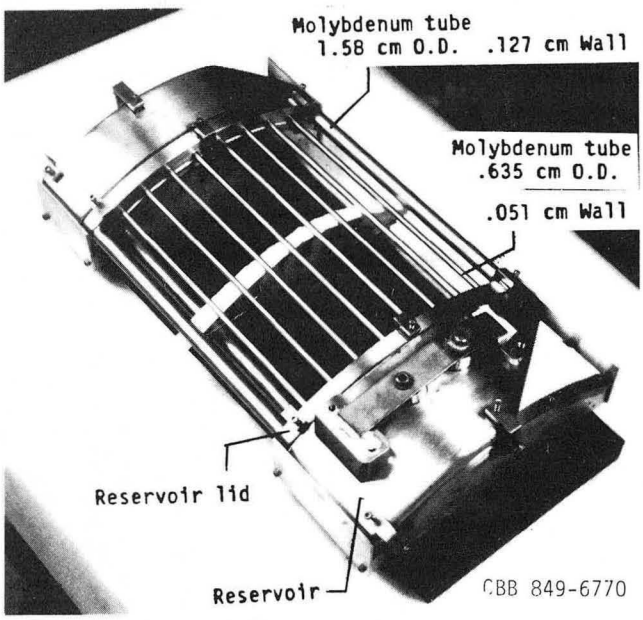

Fig. 7. No. 1 electrode before brazing.

The No. 4 electrode had the same construction, except that the outer tubes were 1.59 cm O.D .07 cm wall stainless steel tubes formed into a "D" shaped cross section. Magnets inside the tubes and a carbon steel flux return frame attached to the flat part of the tubes made up the magnetic circuit for the electron trap. A similar magnetic circuit is part of the No. 3 electrode.

A copper sleeve was used to make the copper to moly tube joint. The thin sleeve extended into the tube and into the copper lid for a distance greater than $2\sqrt{rt}$. The length was choosen so that during brazing, the deformation caused by the differential expansion of the molybdenum tube and the copper sleeve would not affect the far ends of the sleeve. Joints made without the sleeve resulted in leakage.

The solid electrodes are furnace brazed assemblies made up of the reservoirs, cover, and body. The body has cooling water passages machined in the front face, with dimensions as shown in Fig. 5. The brazing was a two step process. The cover was first brazed to the body and then the reservoirs were brazed to the body assembly. Fig. 8 shows electrode No. 3.

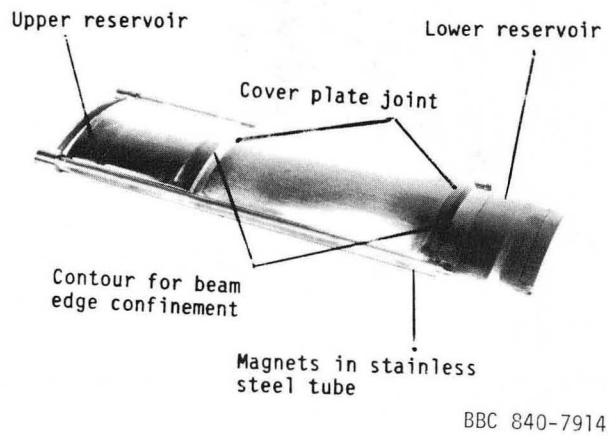

Fig. 8. No. 3 electrode after brazing.

Cryopumps Description

The cryopumps cover all of the available housing wall providing 2.1 m^2 of pumping area.

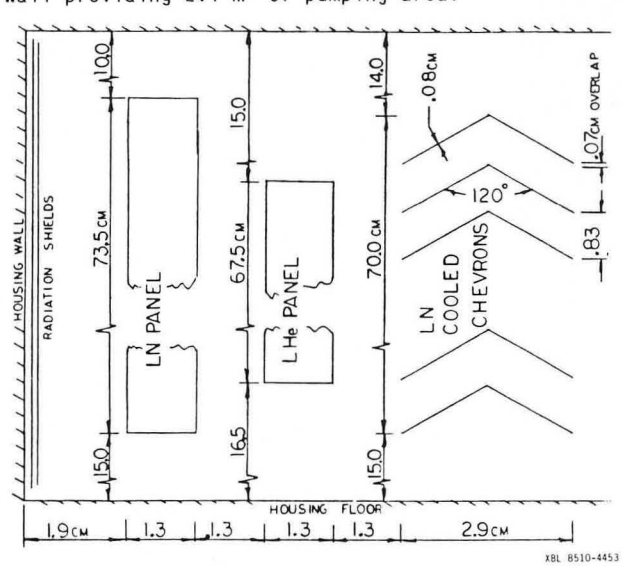

Fig. 9. Cross section of cryopump.

The cryopump are of the conventional design, but very compact, consisting of liquid helium (LHe) panels protected by liquid nitrogen (LN) cooled chevrons on the pumping side and LN cooled solid panels on sides that face the housing wall. Fig. 9 shows a cross section of the panel assembly. The expected LHe and LN consumption is 6 ℓ/hr and 13 ℓ/hr respectively.

Fabrication

Panel: The LN and LHe panels (Fig. 10) are spot welded stainless steel sheets, .09 cm thick, with a 5 cm spot spacing. The sheets are welded to a "U" shaped frame that extends 71 cm in the vertical direction. The frame is the manifold so the liquid enters at the bottom of the panel. To provide flow passages, the panels were hydrostatically inflated at 1200 k Pa to a thickness of 1.3 cm.

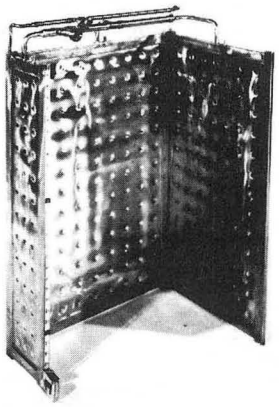

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Fig. 10. LN panel.

Chevrons: The ends of the chevrons were riveted to LN cooled copper bars. Each chevron assembly was then furnace brazed to ensure good thermal contact. The longest chevron assembly has a length of 40 cm. After brazing the chevrons were painted black with Sperex Corp. VHT flat black paint. The paint has a measured emissivity of .8 for 293K thermal radiation.

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